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RECLAMATION

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LAND DRAINAGE
AND
RECLAMATION

BY

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SECOND EDITION

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XI

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PREFACE TO THE SECOND EDITION

Governmental activities related to some of the subjects treated in this book have received tremendous impetus since publication of the first edition in 1928. To keep pace with the progress resulting therefrom, revision is obviously necessary. As heretofore, dominant attention is directed to the practical needs of farmers and farm managers in dealing with problems that arise on individual farms.

Suggestions and advice were sought, with gratifying response, from many regular users of the text for classroom purposes, and the suggestions received were very helpful in preparing the revised manuscript. All were given careful consideration and, in most cases, were adopted.

Aside from the Introduction, which was entirely rewritten, major changes have affected the chapters on Land Clearing and on Control of Erosion. In the first instance, contraction appeared possible without sacrifice of essential data whereas, in the latter, the erosion treatment was rewritten and expanded from one chapter to three. Practically all the new material on erosion was taken from a recent book by one of the authors called "Soil Erosion and Its Control."

Scarcely a chapter was left untouched although the remaining changes were minor and consisted mostly of adding new material and illustrations here and there. The problems at the end of several chapters were clarified and reworded, and in some cases new problems were added. The chapter on Drainage Districts was expanded to include a discussion of Soil Conservation Districts, and certain tables were added to the Appendix.

Especial thanks are due to Larry F. Livingston, Manager, Agricultural Extension Division, E. I. duPont de Nemours & Company, for his kindness in reviewing and slightly revising the chapter on Explosives.

QUINCY C. AYRES,
DANIELS SCOATES.

AMES, IOWA,
August, 1939.

PREFACE TO THE FIRST EDITION

The mission of this book is to fulfill the need for a treatise dealing with the drainage, reclamation, and surveying problems that arise on the average farm and that the farmer himself can well be expected to handle. Primarily, it is intended for the use of agricultural students in the various colleges, but it is hoped that it will be of value to farmers of the country as well; particularly to those who have not had the advantages of a college education. Practicing engineers may also find it useful for reference purposes, but the authors specifically disclaim any intention of presenting the subject in such a way as to produce qualified surveyors or drainage engineers from those who study it.

A sincere effort has been made in Chap. I to acquaint the reader with the broad aspects of land reclamation so as to enable him to obtain a comprehensive grasp of the entire subject. This is desirable, it is felt, in order to prevent unwarranted distortion of the particular phases of reclamation that, later, are dealt with in considerable detail.

In the chapters on surveying, the use of the level and tape is treated at some length, while very little is said about the transit. The reason for this is that most progressive farmers of today possess a level and tape which they are required to use, while a transit is very seldom found or used on the farm. The compass and its use in land surveying, together with the method of making surveys, are discussed in detail, because the farmer should know how this is done for his own protection when dealing with land boundaries and titles. And, further, it is often necessary for the farmer to do this work himself because of the lack of competent surveyors.

In the surface-drainage portion of the text, considerable attention is devoted to the drainage district—the method of forming, how drainage engineers proceed with surveys, and the operation of the district after it is formed. The reason for this is that farmers usually serve as drainage commissioners, and the better informed they are the greater assistance they can give the drainage engineer in the discharge of his duties. Considerable space is given to terracing, because it is realized that this method of conserving soil fertility is rapidly becoming recognized, and it is a matter that the farmer can well handle for himself. The same comment holds true for the two chapters on clearing land. The chapter on useful legal principles, covering laws governing the waters of the farm, is an innovation for a text of this kind, but it seemed to the authors that the average farmer and college student know too little about the laws affecting farm waters, and, as "ignorance of the law excuses no man," a general knowledge of the subject is desirable. The main purpose in the subsurface-drainage part of the text is to present the subject in a form as simple as practicable, eliminating as much mathematics as possible and yet having the material comprehensive and up to date.

Much of the material used in a book of this kind must necessarily be collected from numerous sources. These are accorded credit in the body of the text, in footnotes, or in the list of references appearing at the end of the chapters. The authors are greatly indebted to many individuals and commercial firms for inspiration, counsel, and valuable cooperation in providing illustrations and other material for the manuscript. They wish to acknowledge at this time the cordial assistance of S. H. McCrory, George R. Boyd, H. H. Barrows, C. H. Young, J. A. King, John Swenehart, H. B. Roe, E. R. Jones, J. B. Davidson, R. N. Towl, Wallace Ashby, E. R. Gross, G. E. Martin, J. C. Olsen, M. R. Bently, and many others. Thanks are particularly due to Mr. Boyd, whose generous action in proffering original material, with the sanction of Mr. McCrory, has made the two chapters on clearing land possible. The authors wish also to express their gratitude to The Macmillan Company, John Wiley & Sons, Inc., and other publishers for permitting the use of copyrighted material under their control.

It has been the intention of the authors to present a book which will find a wide application over the entire country, and, as they realize that this first edition will, no doubt, fall short in many particulars, they will be especially pleased to receive criticisms and suggestions for its improvement in subsequent editions. They will very greatly appreciate notice of any errors which may be discovered.

College Station, Texas,
August, 1928.

Q. C. A.
D. S.

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LAND DRAINAGE AND RECLAMATION

CHAPTER I

INTRODUCTION

Land utilized for agricultural production generally requires some kind of artificial treatment to keep it in fit mechanical condition. Very often mere cultivation of the surface is not sufficient and must be supplemented by other basic practices if optimum returns are to be secured and a permanent balance between fertility output and input established. It is as if man's cooperation were expected as a part of the divine purpose in completing the preparation of the world for human habitation.

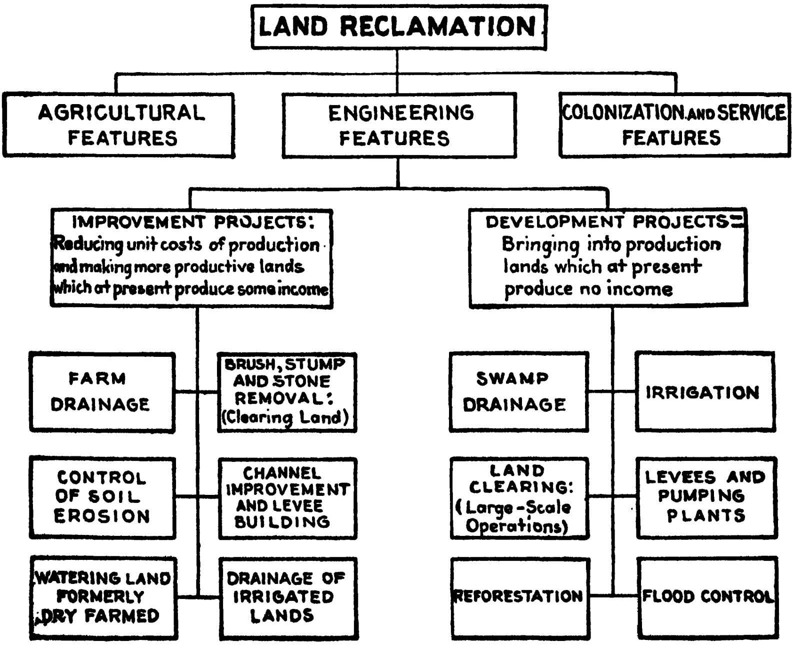
This thought is enhanced by the fact that about three-fourths of the nearly 200,000,000 square miles comprising the earth's surface is water. At least half of the land area is too cold or rocky to support any kind of plant growth, and half of that remaining is too dry or infertile. Thus only about one-sixteenth of the earth's crust is available for growing vegetation, and a large portion of this must permanently be dedicated to forests, shrubs, and grasses, because of excessive steepness, inaccessibility, and other reasons. Much of the land that is left must receive artificial conditioning before it is ready to produce cultivated crops.

Supplementary preparation or conditioning may partake of one or more of the following forms: (1) draining excess water from wet land, (2) preventing overflow on low land, (3) removing obstacles from encumbered land (stones and stumps), (4) applying water to dry land, or (5) retarding run-off from steep land. All these operations have an important place in the field of soil and water conservation and wherever such undertakings have been judiciously conceived and faithfully carried out they have contributed enormously to the well-being and benefit of mankind.

Classification of Projects for Agricultural Production.—The engineering features of land reclamation projects may be subdivided into (1) improvement projects and (2) development projects.

By *improvement projects* is meant the engineering treatment of cultivated land, which already produces some income, in order to lower production costs or safeguard fertility and make it produce more. This treatment may embrace one or more of the following operations: farm drainage, stump and stone removal (clearing land), control of soil erosion, channel improvement, watering land formerly dry farmed, and drainage of irrigated land.

Development projects, on the other hand, contemplate bringing into production lands which formerly produced no income. Such large-scale projects should never be undertaken until after a most careful and painstaking investigation of all the economic and social factors involved. A subdivision of the work generally included under this heading is as follows: swamp drainage, irrigation, land clearing on a large scale, levees and pumping plants, reforestation, and flood control involving projects of great magnitude.


LAND RECLAMATION
AGRICULTURAL FEATURES
ENGINEERING FEATURES
COLONIZATION AND SERVICE FEATURES
IMPROVEMENT PROJECTS: Reducing unit costs of production and making more productive lands which at present produce some income
DEVELOPMENT PROJECTS: Bringing into production lands which at present produce no income
FARM DRAINAGE
BRUSH, STUMP AND STONE REMOVAL: (Clearing Land)
CONTROL OF SOIL EROSION
CHANNEL IMPROVEMENT AND LEVEE BUILDING
WATERING LAND FORMERLY DRY FARMED
DRAINAGE OF IRRIGATED LANDS
SWAMP DRAINAGE
IRRIGATION
LAND CLEARING: (Large-Scale Operations)
LEVEES AND PUMPING PLANTS
REFORESTATION
FLOOD CONTROL

From an engineering standpoint, the difference between improvement projects and development projects is merely one of degree, but economically the distinction is vital. Improving tillable land does not necessarily result in an increase in the total volume of farm products, but it does mean a substantial reduction in unit costs and thus tends to increase the net returns to the farmer. On the whole, only those phases of improvement projects that farmers can easily install for themselves will receive detailed treatment, but enough space will be allotted to development projects to give an insight into the engineering problems involved.

A classification of the entire subject from the point of view of fitting land for agricultural production is shown in diagrammatic form on page 2.

1. History of Land Drainage.—The history of land drainage, like that of many other branches of engineering, can be traced to remote antiquity. As early as 400 B.C., the Greek historian Herodotus speaks indirectly of its application to the Nile Valley in the civilization of the ancient Egyptians. Many Roman writers mention the practice of drainage in some of its phases in most, if not all, of the early Eastern nations. Irrigation and drainage, as well as other valuable practices in agriculture, were well understood and applied, so that today the modern Persians are provided with efficient systems of such installations, though they themselves have long since lost the art.

Cato, Varro, and Virgil all specifically refer to the employment of open ditches as drainage channels, but the first record of underdrainage did not appear until the reign of Augustus. Columella, who lived then, writes of underground causeways and of open and closed ditches 3 feet deep. The closed conduits, he states, should be filled to half their depths with pebbles, stones, or fascines and then covered over with earth. Palladius, who came long after Columella, also describes the underground causeways. For interesting quotations from these ancient Roman authors, the reader is referred to a book on land drainage by John H. Klippart, published in 1867. Other pioneer books on this subject are one by the noted Frenchman, Oliver de Serres, published in 1600, and another by Captain Walter Bligh of England, which appeared in 1652.

The two spectacular accomplishments of the Old World most frequently quoted by drainage authorities are the Fens of

England and Haarlem Lake of Holland. These are both monumental undertakings, and their unqualified success has doubtless had some influence in the formation of similar enterprises in this country.

Encouraged by the success of Haarlem Lake, the Dutch government has launched and is now engaged in prosecuting the mighty Zuider Zee project, which, when completed, will open for settlement more than ten times the area and accommodate nearly twenty times as many people as Haarlem Lake. The work involves extending the coast line out into the sea by means of dikes built under water and then pumping the enclosed area dry. Four such enclosures, or polders, are contemplated east and north of Amsterdam, varying in size from 50,000 to 235,000 acres each. The land to be reclaimed lies from 1 to 15 feet below the level of the North Sea, and internal drainage will be accomplished by the use of subsidiary dikes, ditches, pumping plants, and tide gates. The estimated cost of $210,000,000 (nearly $400 an acre) includes the construction of 18 miles of main dikes as well as the pumping plants, auxiliary structures, and special methods of caring for the soil and preparing it for crops. In the economy of Holland this is not considered an exorbitant charge. The undertaking is being financed by the government and is expected to be completed gradually over a period of 20 years.

The history of nearly every European country contains records of completed drainage enterprises which, though not so large in single units and consequently not so spectacular as the ones just mentioned, nevertheless constitute projects of considerable national importance. The Pontine Marshes of Italy as well as the projects of La Geronde and Forez in France are notable examples of this kind of activity. During the last 3 years the Germans have spent $320,000,000 to reclaim new land, and they announced in 1938 that another $400,000,000 is to be expended for land reclamation work and the increased use of fertilizers.

2. Drainage in the United States.—Events of all kinds transpire with such surprising rapidity in the United States that we need to adjust our focus somewhat when viewing the drainage development of our own country. About a century ago (1835), the first drain tile were laid in the United States. These were handmade tile and were installed on the farm of the "the father of tile drainage," John Johnston, a Scotchman of Geneva, N. Y. In 1848 the first drain-tile machine was imported from England;

and 10 years later, 856 acres in Central Park, New York City, were successfully drained.

From these early beginnings, the spread of land drainage was rapid, first in a westerly direction through the East Central and Midwestern states but later engulfing the entire humid region of the North, East, Middle West, and South.

Certain developments have taken place during the past century that have had a distinctly stimulating effect on the progress of land drainage. These are:

1. The invention of a drain-tile machine and its introduction into the United States, in 1848.
2. The enactment of state laws providing the legal machinery for the operation of community outlet projects.
3. The perfection of excavating machinery during the latter part of the nineteenth century.
4. The establishment of numerous drain-tile factories throughout the country.
5. The formation of state, sectional, and national associations of interested landowners, engineers, and others for the interchange of experiences and ideas.
6. The work of state and national research organizations, which by painstaking investigations have made important contributions to our store of scientific knowledge.
7. The labor of extension workers of state colleges and of engineers of the U. S. Department of Agriculture who have, by actual demonstration in the field, convinced many backward communities of the value of drainage.
8. The publication of numerous circulars and bulletins on the subject, which, together with personal correspondence and, in recent years, the use of the radio, have done much to broadcast information and stimulate activity.

Successful drainage improvements perform their service in an inconspicuous manner. Being largely buried out of sight and functioning noiselessly, they attract very little attention, so that it is difficult for the present generation of Americans to visualize the original condition of large areas of what is now our very best productive land. It is interesting to contrast present conditions with those described in early accounts of pioneer adventures such as the book by Keating published in 1825 under the title "Long's Expedition to the Source of St. Peters River in 1823." The following passage is typical of the experiences reported:

> Near to this house we passed the state line which divides Ohio from Indiana. The distance from this to Fort Wayne is 24 miles without a settlement; the country is so wet that we scarcely saw an acre of land

upon which a settlement could be made. We traveled for a couple of miles with our horses wading through water, sometimes to the girth. Having found a small patch of esculent grass (which from its color is known here by the name of bluegrass), we attempted to stop and pasture our horses, but this we found impossible on account of the immense swarms of mosquitoes and horse flies, which tormented both horses and riders in a manner that excluded all possibility of rest.

After reading this description, and many others like it, it is easy to see why drainage, by both open ditches and tile drains, was soon recognized as a fundamental prerequisite to provide an environment suitable for human habitation as well as conditions necessary for the growth of crops. Without drainage it is literally true that much of the most prosperous agricultural area in the country could not successfully have been settled, nor would highways, railways, schools, sewerage systems, or the thousands of other individual and community activities which we speak of as civilization have been possible.

3. Drainage Census Data.—The first census of drainage in the history of the United States was taken by the federal government in 1920 and was repeated in 1930. Complete results are available in printed form and at nominal cost on application to the Superintendent of Documents at Washington, D. C.

Before attempting to make an analysis of these statistics, the interpreter should keep in mind certain distinctions underlying their collection, *i.e.*, the differentiation between drainage on farms (private drainage) and community enterprises (public drainage), which was clearly recognized and observed.

Drainage on farms is that kind of direct drainage which the individual farmer has executed or is capable of executing by his own unaided efforts. The outlet of such a system may be either into a natural channel or into an artificially constructed waterway. Information relating to drainage of this character was collected by regular census enumerators at the same time and in the same manner—by personal canvass—that other agricultural data were gathered.

On the other hand, statistics regarding community enterprises were concerned only with outlet projects where groups of landowners had combined to secure potential benefits which were impossible of attainment by individual effort. Most of these districts had been organized and conducted under state laws which provide specific regulations governing their procedure.

TABLE 1.—DRAINAGE SUMMARY FOR THE UNITED STATES: 1930 AND 1920

Item	Census of		Increase[1]	
	1930	1920	Amount	Per cent
Farms and drainage on farms:				
All farms	6,288,648	6,448,343	−159,695	−2.5
Farms reporting drainage	651,172	924,815	−273,643	−29.6
All land in farms, acres	986,771,016	955,883,715	30,887,301	3.2
Farm land provided with drainage, acres	44,523,685	53,024,975	8,501,290	−16.0
Area, drains, and investment in enterprises, acres:				
Approximate land area of 35 states reporting organized drainage enterprises[2]	1,743,699,840	1,717,932,160	25,767,680	1.5
Land in drainage enterprises	84,408,093	65,495,038	18,913,055	28.9
Improved land	63,514,081	44,288,235	19,225,846	43.4
Unimproved land:				
Woodland	11,310,402	11,283,532	26,870	0.2
Other	9,583,610	9,923,271	−339,661	−3.4
Land unfit to raise any crop for lack of drainage	7,396,078	7,224,213[3]	171,865	2.4
Land drained, fit to raise normal crop	66,234,390	([4])		
Land partly drained, fit for partial crop	10,777,625	3,011,407[5]	7,766,218	257.9
Land in occupied farms	68,640,109	([4])		
Land in planted crops	54,427,577	([4])		
Land idle	20,003,315	([4])		
Ditches, completed, miles	138,674.0	107,468.2	31,204.8	29.0
Tile drains, completed, miles	55,031.9	42,311.7	12,720.2	30.1
Capital invested in enterprises	$680,732,880	$372,273,567	$308,459,313	82.9
Average, per acre	$8.06	$5.68	$2.38	41.9

---

[1] A minus sign (−) denotes decrease.

[2] The 35 states which reported organized drainage enterprises in 1930 are Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, Wisconsin, and Wyoming. In 1920, all these states except Virginia were included in the drainage census.

[3] "Swampy, subject to overflow, seeped, or alkali."

[4] Not called for on schedule.

[5] "Suffering a loss of crops from defective drainage."

Since the records on file at the various county seats contained all the details of each such project, the compilation of essential data became a relatively simple matter. This work was done by special enumerators appointed for the purpose.

At this point it should be said that much confusion and some dissatisfaction have arisen among owners owing to a failure to comprehend the limited objectives of district organization. For reasons which will appear later, drainage districts are empowered to perform only that kind of service for the individual that he is powerless to perform for himself, *i.e.*, to provide easily accessible outlets. The obligation of the district to the individual ends here. Obviously, little or no benefit will accrue to the owner until he takes advantage of his outlet privilege by installing lateral drains, notwithstanding the tax he pays for his share of the cost of construction.

Table 1 gives in compact form a summary of drainage data collected in 1920 and 1930. With one minor exception, all the decreases noted refer to the data that were collected by personal canvass and are hence more or less subject to guesswork. It would be interesting to know how many of the 159,695 fewer farms reported in 1930 were farms retired because of excessive erosion. It has been generally conceded that the period from 1920 to 1930 was relatively inactive from the standpoint of new projects, yet the figures show about 30 per cent increase in the mileage of both open ditches and tile drains and 83 per cent increase in invested capital. About half of the latter amount was spent for new projects. Only about one-ninth of all the land in drainage enterprises had failed to pay interest and principal in full on outstanding debts.

A summary of the drainage work accomplished by organized enterprises in the various states is given in Table 2, and the rate of development from 1870 to 1930 is shown in Table 3.

4. Non-agricultural Drainage.—With the beginning of the era of industrial expansion in the last half of the nineteenth century many new applications were found for drainage. One of these was the safeguarding of foundations. It was known that the bearing power of soils of all kinds was greatly reduced by the presence of excess moisture. Diversion of surface water and drainage of ground water from the vicinity of bridge abutments and building foundations soon came to be one of the most important services rendered by drainage.

TABLE 2.—SUMMARY OF DRAINAGE WORK OF ORGANIZED DRAINAGE ENTERPRISES BY STATES[1]

State	Land in enterprise, acres	Improved land in enterprise, acres	Length of ditches, miles	Tile drains, miles	Levees, miles	Pumping plants, horsepower	Capital invested
Ohio	8,165,494	7,604,274	25,048	9,371	0	25	$ 36,836,449
Indiana	10,214,014	9,361,457	20,787	10,439	132	166	54,110,854
Illinois	5,032,682	4,745,840	5,996	3,826	1,108	18,658	75,048,548
Michigan	9,180,851	7,663,256	17,189	3,490	35	275	37,677,084
Minnesota	11,474,683	7,396,575	14,478	9,451	150	75	64,139,641
Iowa	6,137,649	5,961,454	4,800	13,382	113	4,625	77,478,893
Missouri	3,150,022	2,309,267	4,961	123	931	2,533	47,340,174
North Dakota	1,094,142	1,075,259	818	10	0	0	3,148,919
Florida	5,954,934	783,033	5,113	0	718	5,065	45,487,795
Mississippi	2,988,496	1,950,356	4,022	44	228	370	23,601,443
Arkansas	4,631,155	2,614,427	4,974	0	202	515	37,532,575
Louisiana	3,655,483	2,267,737	7,701	2	576	6,495	20,752,645
Texas	2,833,356	2,011,044	3,662	9	216	510	12,002,949
California	2,233,714	2,007,987	4,606	486	1,390	41,748	66,451,698
Other states	7,661,418	5,762,115	14,519	4,399	740	18,687	79,123,213
Total of U. S.	84,408,093	63,514,081	138,674	55,032	6,539	99,747	$680,732,880

---

[1] From U. S. Drainage Census of 1930.

TABLE 3.—AREA AND CAPITAL BY DATE OF ORGANIZATION

Date of organization	Land		Area of enterprises		Capital invested to Jan. 1, 1930	
	Acres	Per cent	Acres[1]	Overlapped acres	Total	Per acre
All enterprises	84,408,093	100	128,495,078	44,086,985	$680,732,880	$5.29
Before 1870	919,117	1.1	1,056,844	137,727	$ 1,263,389	$1.20
1870–1879	2,516,942	3.0	3,480,915	963,973	11,317,896	3.25
1880–1889	6,052,807	7.2	9,549,227	3,496,420	28,035,384	2.94
1890–1899	5,957,503	7.0	11,265,052	5,307,549	32,838,911	2.92
1900–1904	7,665,823	9.1	12,380,936	4,715,113	34,139,656	2.76
1905–1909	18,328,017	21.7	23,862,554	5,534,537	111,612,254	4.68
1910–1914	16,448,377	19.5	22,331,693	5,883,316	125,953,183	5.64
1915–1919	15,802,902	18.7	23,422,034	7,619,132	190,583,008	8.14
1920–1924	7,428,179	8.8	12,735,739	5,307,560	102,976,838	8.09
1925–1929	3,288,426	3.9	8,410,084	5,121,658	42,012,361	5.00

---

[1] Includes overlap.

Drainage to protect structures finds perhaps its largest application under railroads and highways. Because of their physical character, modern rail lines, pavements, and smooth roads would be unknown if means of preserving their stability and protecting them against washout had not been developed through drainage.

In the municipal field, drainage is important from several standpoints. The control and quick removal of surface and ground water is essential to personal comfort and public health; to the uninterrupted flow of commerce, industry, and business in general; and to the protection of all kinds of public improvements.

Other needs for drainage are found on athletic fields, golf courses, race tracks, aviation fields or airports, and similar developments where special use results in high value and large justifiable expenditures for drainage.

Drainage for the prevention of malaria has a well-established technique; the transmission of the disease has been traced to a night-biting mosquito whose breeding habits have been learned, and methods to prevent its production, largely by drainage, are known. Together with house-screening and medical elimination of the acute disease from infected persons who serve as malaria carriers, such drainage is of high economic value in settled areas. It must follow a special technique and usually must supplement drainage for land reclamation.

Drainage for abatement of pest varieties of mosquitoes, not involving public health consideration, also has a special technique. Generally only very shallow lowering of the ground water horizon is necessary or economically justifiable. The preservation of area values for wild life refuge and breeding is in many cases a major economic consideration, too often overlooked by inexperienced designers. Well-constructed projects have proven of high economic value through increased values of residential property, increased field-worker efficiency, and increased milk yield of dairy herds.[1]

5. Irrigation.—The artificial application of water to dry lands is, like drainage, an art as old as agriculture itself. Crude water wheels, archimedean screws, and other primitive devices operated by hand are still used today in the rice fields of China and along the banks of the Nile much in the same manner as thousands of years ago. Although irrigation is practiced to some extent in nearly two dozen countries of the world, acreages in excess of 5,000,000 are limited to the seven nations of China, India, the

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[1] Report of the Water Planning Committee, National Resources Board, Dec. 1, 1934, p. 341.

United States, Russia, Japan, France, and Egypt. China and India lead with 50,000,000 and 40,000,000 acres, respectively. The United States is next with 20,000,000 acres, and the other four countries have less than 10,000,000 each.

Inspection of Table 4 will give an accurate idea of the irrigation situation in the United States as it existed at the time

TABLE 4.—CENSUS SUMMARY FOR THE 19 IRRIGATION STATES: 1930 AND 1920

Item	Census of		Increase[1]	
	1930	1920	Amount	Per cent
All farms	2,062,813	1,916,391	146,422	7.6
All land in farms, acres	568,693,705	505,440,954	63,252,751	12.5
Approximate land area, acres	1,223,989,120	1,223,989,120		
Farms irrigated	265,147	222,789	42,358	19.0
Area irrigated, acres	19,547,544	19,191,716	355,828	1.9
Area enterprises were capable of supplying with water, acres	26,101,890	26,020,477	81,413	0.3
Area in enterprises,[2] acres	30,599,470	35,890,821		
Proportion irrigated, per cent:				
All farms	12.9	11.6		
All land in farms	3.4	3.8		
Approximate land area	1.6	1.6		
Excess of area enterprises were capable of supplying with water over area irrigated, acres	6,554,346	6,828,761	−274,415	−4.0
Excess of area in enterprises[2] over area irrigated, acres	11,051,926	16,699,105		
Area of irrigated land available, or to be available, for settlement, acres	1,681,598	2,257,981	−576,383	−25.5
Value of irrigated farms [land, buildings (including dwellings), and implements and machinery]	$4,886,892,784	(3)		
Investment in irrigation enterprises	$1,032,755,790	$697,657,328	335,098,462	48.0
Average, per acre, based on area enterprises were capable of supplying with water	$39.57	$26.81	12.76	47.6
Estimated final cost of existing enterprises	$1,155,108,210	$819,778,005	335,330,205	40.9
Average, per acre, based on area in enterprises[2]	$37.75	$22.84		
Average annual cost, per acre, for maintenance and operation of irrigation works	$2.77	$2.43	0.34	14.0

States included: Arizona, Arkansas, California, Colorado, Idaho, Kansas, Louisiana, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming.

[1] A minus sign (−) denotes decrease.

[2] Irrigable area, 1930; total area, 1920.

[3] Figures not available.

of the last census. Comparison with Table 1 will show that the capital invested in irrigation enterprises is about 50 per cent more than that invested in drainage and that the average cost per acre is nearly five times as great. The annual value of crops grown in the 19 irrigation states (all of which lie wholly or partly west of the hundredth meridian, except Arkansas and Louisiana) approximates $1,000,000,000.

Prior to the war between the states less than 500,000 acres was irrigated in the United States, but beginning in 1860 an average of nearly 3,000,000 acres was added to the irrigated area in each decade. The largest increase of 4,511,576 acres occurred in the period 1900 to 1909, while the smallest increment since 1870 (1,588,542 acres) was added from 1920 to 1929. Most of the early projects, totaling more than 12,000,000 acres, were developed as individual and partnership enterprises and by voluntary cooperation between groups of farmers, but, as the difficulty and cost of providing water mounted, state district laws were enacted, and the federal government took cognizance of the situation. State irrigation districts have since included 3,452,275 acres, and about 2,000,000 acres additional have been developed to 1930 by various federal agencies, principally the U. S. Bureau of Reclamation.

This bureau was established in 1902 as the U. S. Reclamation Service, and an enormous amount of work has been accomplished under its direction. During the 35 years of its existence ending June 30, 1937, the following structures were built: 138 storage and diversion dams; 24 powerhouses; 2,344 buildings; 19,116 miles of canals, ditches, and drains; 72½ miles of tunnels; 4,367 miles of telephone lines; 267 miles of dikes and levees; 6,041 flumes; 18,694 culverts; 13,166 bridges; and 182,964 weirs, measuring devices, and other irrigation structures. Each major dam seems to surpass in size and daring the one that went before.

The two latest giants are Boulder and Grand Coulee dams, both of which exceed by far in height and magnitude any dam in the world. Next in height is the 405 foot Owyhee Dam in Oregon, which was completed in 1932. Boulder Dam will raise the water surface of the Colorado River 582 feet and contains 3,400,000 cubic yards of concrete in the dam proper and 1,000,000 cubic yards additional in the power plant and appurtenant works. It is 1,180 feet long at its crest. The reservoir when full will impound 30,500,000 acre-feet of water, which is expected to provide for 2,100,000 acres of irrigable land as well as for the other stated purposes of flood control on the Colorado, general river regulation, silt control, power development, and domestic water supply. The Boulder Canyon Project Act authorizes appropriations not to exceed $165,000,000, divided as follows: dam and reservoir, $70,600,000; power development, $38,200,000; All-American Canal, $38,500,000; and interest during construction, $17,700,000.

Grand Coulee Dam, located in the state of Washington, will be 550 feet high and will contain 11,225,000 cubic yards of concrete. It will impound 208,000,000 acre-feet of water. The cost for the dam and appurtenances is estimated at $119,000,000, and for the power plant, $67,000,000.

So far as irrigation is concerned, these vast governmental expenditures are justified in part on the ground of national solidarity. Each farm family is said to support and require the services of three other families in some near-by town or city to supply those things that constitute the American standard of living. Moreover, the agricultural products grown under irrigation compete only to a limited extent with products grown in other parts of the country, partly because of the special nature of the crops (citrus fruits, etc.) and partly because the crops come on the market during off-season periods elsewhere.

On the other hand, it is a fact that many settlers as well as investors in irrigation securities have been oversold on the possibilities of irrigation farming by overzealous promoters. To "make the desert bloom as the rose" the newcoming settler requires special knowledge, special equipment, special structures and land preparation, and a reasonable amount of capital to tide him over until returns begin to come in. The theory behind the U. S. Reclamation Service activities was that a revolving fund would soon be created by installment payments from settlers on the older projects and that this money would then be used to finance new projects for an indefinite period without further appropriations by the government. Unwillingness and inability to make these payments precipitated a crisis in 1922, at which time major readjustments were made and the Reclamation Service was reorganized to give greater emphasis to the agricultural and economic phases of irrigation developments. At that time the name was changed to the U. S. Bureau of Reclamation.

TABLE 5.—AREAS WHICH WOULD BE BENEFITED BY AND AREAS NOW RECEIVING SUPPLEMENTARY IRRIGATION IN VARIOUS STATES[1]

State	Area which would be benefited, acres	Area now irrigated, acres	Remarks
California......	500,000	20,000	Estimate by Frank Adams for coast counties north of San Francisco
Idaho..........	15,000	8,000	In the Palouse region and northern Idaho
Illinois..........	10,000	630	
Indiana.........	10,570	1,756	Water from streams, few wells
Iowa............	20,000	2,500	Water from wells, rivers, lakes, and city supplies
Kansas.........	4,500,000	95,000	Tying in the Arkansas and Kansas River valleys. 30% of present irrigation is from wells. Corn, alfalfa, and truck crops need irrigation because of the almost regular occurrence of 30 to 60 days of dry weather in July and August
Michigan.......	20,000	7,600	Ample supply of ground water
Minnesota......	40,000	895	Water to be pumped from streams, lakes, and wells
Nebraska.......	1,457,000	200,000	Two-thirds of the area needing irrigation and most of the irrigated area is the Platte River Valley. Remainder is on the Republican and Loup rivers. Estimates by Clark E. Mickey
New Jersey.....	....	6,000	
Ohio............	37,000	10,100	
Oregon.........	1,000,000	5,000	Chiefly in Willamette Valley
Texas..........	....	....	Several projects of 10,000 to 150,000 acres are proposed on lands now dry farmed
Virginia........	....	3,600	
Washington.....	50,000	10,000	In Puget Sound and Palouse regions
Wisconsin......	2,000	40	Water to be pumped from lakes and streams

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[1] Estimates by A. S. A. E. committee, 1931–1936. 1937 investigations showed an increase over 1936 of 4,500 acres in 10 of the definitely humid states.

Advantages of supplemental irrigation in the Willamette Valley of Oregon, where rainfall averages 40 inches a year, are given as follows: (1) controls soil moisture and overcomes drouth; (2) provides green pasture and green feed late in the summer; (3) saves the clover stand and makes a cutting the first season; (4) makes double cropping possible—late crops after early crops; (5) aids the beneficial bacteria and chemical activities in the soil; (6) aids control of crop pests and diseases; (7) increases efficiency of soil moisture during the best growing weather; (8) is an aid to deep or early plowing and intensive cropping; (9) softens clods and dissolves plant foods; (10) if properly planned, pays in increased yields, net profits, and productive values.

Irrigation installations are expensive. They often cost as much as the land they water and sometimes much more, but instances have occurred where one year's increase in crop value has paid the entire capital cost of the outfit. Data collected in Michigan show that the increase in yield of potatoes due to irrigation ranges from 50 to 150 bushels per acre. An apple orchard in Ohio in 1932 yielded 290 bushels per acre on non-irrigated land and 360 bushels on irrigated land. The irrigated orchard returned $90 per acre above the cost of irrigation. A field of irrigated potatoes in New Jersey in 1933 yielded 270 bushels compared with 146 bushels on an unirrigated field. In 1932 an apple orchard in Georgia yielded $4 per tree more than unirrigated apples. An 80-acre field of alfalfa in Virginia, for which irrigation was provided at a cost of $1,200, is reported to have returned $2,400 from one cutting. The owner of a 60-acre apple orchard in Virginia estimated that the increased yield in 1 year was worth more than the cost of the irrigation system.

Against these isolated examples showing what has happened under very favorable conditions may be set numerous cases in which the increased yield obtained by irrigation has not been sufficient to justify the investment. In many cases an owner has considered the benefits of irrigation not sufficient to pay the running expenses and upkeep and has abandoned the plant.[1]

7. Soil-erosion Control.—According to estimates of the U. S. Bureau of Chemistry and Soils and other authentic sources, an erosion inventory of the United States is as follows:

Thirty-five million to 50,000,000 acres of once fertile cultivated land totally ruined and abandoned in 1937 as compared with 10,000,000 acres in 1910.

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[1] Report of the Mississippi Valley Committee of the Public Works Administration, Oct. 1, 1934, p. 80.

Partial to complete stripping of topsoil on 100,000,000 to 125,000,000 acres of remaining cultivated land.

Approximately 500,000,000 tons of suspended silt annually transported to river mouths, in addition to vast quantities of soil and sand from uplands that never reach the open seas but spread out and lodge on rich bottom lands and choke culverts, public streams, and reservoirs. The Mississippi River alone annually disgorges into the Gulf of Mexico a volume of silt equivalent to a depth of 330 feet over an area of 1 square mile, which, assuming a weight of 80 pounds per cubic foot, amounts to 368,000,000 tons.

Two hundred and seventy million tons of dissolved matter containing 63,000,000 tons of plant-food material removed from the fields and pastures of the United States and delivered to the oceans every year. This represents a rate of fertility exhaustion twenty-one times greater than that required to produce a crop of corn.

Overgrazing on 165,000,000 acres of the public domain, which has lost from 40 to 50 per cent of its productivity in consequence. That 640 acres is too small a unit for stock grazing is attested by the virtual destruction of all grass on the sparsely covered range; and 15,000,000 acres of abandoned homesteads testifies to the futility of attempt to cultivate land suited only for grazing.

Six inches or more of topsoil washed off many cultivated fields in a generation of farm life is a common experience in the Southeastern states, according to the U. S. Bureau of Agricultural Engineering.

In one old South Carolina piedmont county 90,000 acres of formerly good land has been ruined by gullies. And 46,000 acres of bottom land, once the richest soil in the state, has been so covered and otherwise damaged by deposits from the upland farms that they are now mainly useless. A Georgia piedmont county has suffered in much the same way: 100,000 acres of former crop land in the upland region has been so badly washed that it is now about worthless for anything except trees; erosion is still cutting steadily into every cultivated sloping field.

And so the story goes. Six million acres terraced in Texas alone is some indication of the severity of the problem in that state and also of the enterprise of Texans in meeting it. One of the first systematically conducted erosion surveys in the country took place in Oklahoma in 1929, where enormous losses

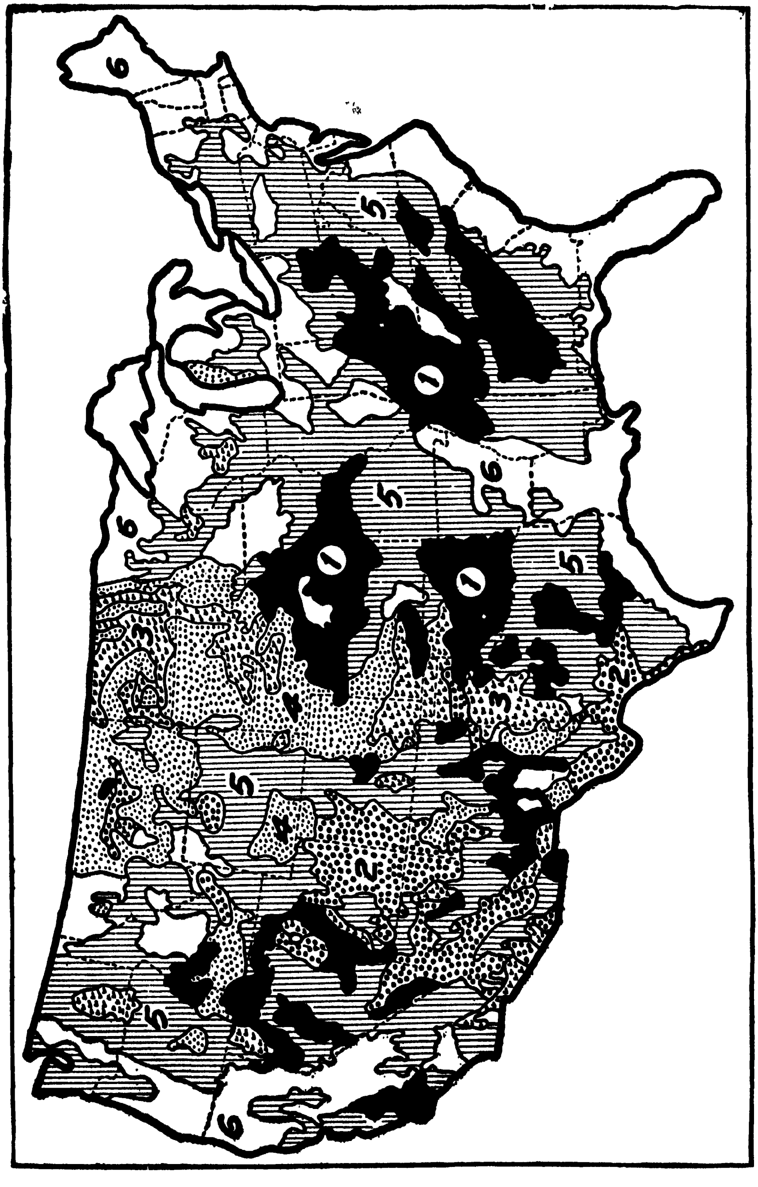

FIG. 1.—Map showing location, extent, and severity of erosion in the United States. 1. Severe sheet and gully erosion. 2. Moderate to severe erosion, includes mountains, mesas, canyons, and badlands. 3. Moderate to severe wind erosion, some local gullying. 4. Slight wind erosion, moderate sheet and gully erosion. 5. Moderate sheet and gully erosion, serious locally. 6. Erosion unimportant, except locally. (*U. S. Soil Conservation Service data*, 1936.)

were revealed; the vulnerability of southern California farm land has long been recognized; and probably some of the most disheartening examples of ultimate erosion to be found anywhere are located in the red clay hills of Mississippi and Alabama. Erosion is truly as widespread as man's efforts to exploit sloping lands.

A reconnaissance survey of erosion on all land in the entire country was conducted by the U. S. Soil Conservation Service in 1934 and 1935 with the results shown in Table 6. The location and distribution of lands in the various erosion classes can be noted from Fig. 1. Because of overlapping within the several classes, the figures in the last column add to more than 100 per cent.

Table 6.—Summary of Erosion Conditions in the United States

Erosive condition	Acres	Percentage of total area of the United States	
Area with little or no erosion	576,236,371	....	30.3
Total area affected by sheet erosion	855,260,347	....	44.9
¼ to ¾ of topsoil gone	663,199,473	34.8	
Over ¾ of topsoil and some subsoil gone	192,060,874	10.1	
Total area affected by wind erosion	322,181,740	....	16.9
Moderate wind erosion (some gullying)	233,321,336	12.2	
Severe wind erosion (some gullying)	79,659,052	4.2	
Destroyed by wind erosion (some gullying)	9,201,352	0.5	
Total area affected by gullying[1]	864,818,281		45.4
Occasional gullies (with sheet erosion)	523,351,168	27.5	
Severe gullying (with sheet erosion)	337,305,021	17.7	
Destroyed by gullying (with sheet erosion)	4,162,092	0.2	
Rough mountain lands, canyons, and rock outcrop	144,768,315	....	7.6
Total area exclusive of large cities and water	1,903,176,620	....	

[1] In the Western states much gullying is normal geological dissection, on which erosion may be, but is not necessarily, active.

From the foregoing it is seen that erosion produces losses in three distinct categories: (1) valuable plant food in solution, (2) fine silt and humus in suspension, and (3) removal by scour of the soil itself. Potentially an area exceeding one-third of the entire cultivated acreage of the United States is either totally ruined, or soon will be, unless the erosion menace is subjected to vigorous, concerted, and unremitting attack on a nation-wide front.

Erosion-control measures result in great benefit both to the private owner and to the public; to the landowner in the form of soil and moisture conservation, and to the public in the form of reduced flood heights, clearer streams, and lower maintenance charges for bridges and culverts, drainage ditches, and navigable waterways. Furthermore, adjoining owners of level lands are insured against overwash by barren soil from already denuded slopes, and there is a vital community interest in maintaining the ability of all citizens to pay their pro rata share of the tax burden.

Estimates by a distinguished committee of the National Resources Board place the tangible money loss suffered by citizens of the United States on account of erosion at $400,000,000 annually. In the judgment of the committee this justifies a federal expenditure of $20,000,000 a year for erosion control and prevention.

8. Flood Control.—Each year the flood losses in the United States are sufficient to attract attention. The losses sustained throughout the country in 1911 have been estimated at $200,000,000; those of 1912, at $250,000,000; and those of 1913 exceeded even the latter amount. Every 10 or 15 years, at least 2,000 lives are lost and many millions of dollars' worth of property destroyed by floods of American rivers. Some of the most memorable were:

The overflow of the Mississippi in April, 1912, with a loss of 500 lives and destruction of $3,000,000 worth of property in scores of towns and cities in Louisiana, Mississippi, Arkansas, and Tennessee. Again, in 1913, a flood of equal magnitude occurred. The next great Mississippi flood came in 1920; another in 1922, while in 1927 all records of previous high water, covering a period of 39 years, were exceeded.

In March, 1913, the Ohio and its tributaries overflowed with serious effects on a large region including Dayton, Hamilton, Zanesville, Columbus, and Cincinnati. In Ohio alone, 452 lives were lost, and property damage exceeded $20,000,000.

More than 250 persons lost their lives in a flood which overran the valley of the San Luis Rey River in California, in January, 1916.

Flooding of Pueblo and other Colorado towns in 1921 has been described as the worst disaster that has befallen this country since the sinking of the steamship "Eastland" at Chicago in 1915 with a loss of 812 lives.

In fact, the history of practically every stream in the United States is replete with flood stories of greater or less significance. The disastrous consequences following the 1935 and 1936 floods in the New England states and the great flood of 1937 in the Ohio and Mississippi rivers are of too recent occurrence to require more than bare mention.

Protecting agricultural lands and city property from the ravages of floods is an engineering problem of the first magnitude, frequently requiring years of painstaking study and millions of dollars' expenditure for its satisfactory solution. The work of the engineers of the Miami Conservancy District in Ohio is, perhaps, the outstanding example of flood protection on a large scale that has yet been attempted in this country, where the work was financed by private capital.

9. Cut-over Land.—There are 500,000,000 acres of forest and arid woodland in the United States, including cut-over and burned-over land. About one-half of this is in the South, one-eighth in the Northeastern states, one-eighth in the Lake states, and nearly one-quarter is in the West. Allowing for areas suitable only for permanent forest, there remains about 228,509,000 acres which can be used for other purposes. The most reliable estimate available distributes this land among the various states as shown on page 23.

Of this amount, upward of 188,000,000 acres is classified as available for crops under extreme conditions, but it is very unlikely that much more than half of this will ever be put under the plow. The balance will probably be devoted permanently to such other uses as reforestation, unimproved pasture and range land, wild-game preserves, recreation parks, and the like. It seems reasonable to state that, after making full allowance for cut-over land better adapted for purposes other than agricultural production, as well as for overlapping of cut-over land with timbered swamp land, 50,000,000 acres remains to be cleared of brush and stumps and developed into choice farm land. Economic forces will no doubt determine when and how this vast area will be reclaimed.

Table 7.—Distribution of Cut-over Land by States

State	Acres
Alabama	14,785,000
Arkansas	13,893,000
California	3,031,000
Florida	10,109,000
Georgia	20,141,000
Idaho	676,000
Kentucky	3,222,000
Louisiana	11,877,000
Maine	6,135,000
Maryland	1,848,000
Michigan	11,686,000
Minnesota	14,022,000
Mississippi	13,203,000
Missouri	8,900,000
Montana	674,000
New Hampshire	2,608,000
New Jersey	1,151,000
New York	5,997,000
North Carolina	12,745,000
Oregon	3,537,000
Pennsylvania	5,297,000
South Carolina	8,994,000
Tennessee	7,833,000
Texas	12,936,000
Vermont	2,070,000
Virginia	9,929,000
Washington	3,330,000
West Virginia	4,634,000
Wisconsin	13,246,000
Total	228,509,000

It would be a mistake to assume that all these 50,000,000 acres occur in large tracts. Nearly every farm in some sections of the country contains more cut-over land than is strictly required for the purposes of a wood lot. And a great many farms in cut-over regions do not contain a sufficient amount of cleared land to justify the efforts of the persons working them. If the process of clearing is only partially complete and the attempt to cultivate land covered with stumps is made year after year, the farmer is fighting a losing battle from the start. A surprisingly large number of farmers in cut-over areas have little or no chance to make money farming, because the amount of cleared land which they have is not sufficient to support profitably the type of farming in which they are engaged.

10. Conservation Economics.—Many of the ideas and suggested studies regarding use of land in the United States that were mentioned in the 1928 edition of this book have since been carried out. Numerous fact-finding and policy-planning agencies have built up some rather voluminous literature on the subject. One of the objectives in each case has been to gather together all existing data concerning land and water resources and to work out as many alternative plans of procedure as possible, taking into account probable population changes and other social and economic trends over long periods of time. The need for much additional information has thus been made apparent, and not the least valuable outcome of the studies has been the compilation and recommendation of long-range surveys and investigations to supply the missing basic data.

The National Resources Committee, as at present constituted, represents a coalition of the National Planning Board, the National Resources Board, and the Mississippi Valley Committee. Before the merger each of the two last rendered elaborate reports, notably the Report of the Mississippi Valley Committee issued in October, 1934, and the Report of the National Resources Board of December, 1934. These documents include the work of many cooperating federal and state agencies together with that of special subordinate committees. These and other similar reports are obtainable from the Superintendent of Documents, Washington, D. C., at a small price.

As an example of the magnitude of the tasks undertaken and the thoroughness with which the work is being done the 539-page report of the Water Resources Subcommittee of the National Resources Committee is cited. The investigation on which the report is based was undertaken (1) to determine "the principal water problems in the various drainage areas of the country"; (2) to outline "an integrated pattern of water development and control designed to solve these problems"; and (3) to present "specific construction projects and investigation projects as elements of the integrated pattern or plan, with priorities of importance and time." The report was published in December, 1936, under the title "Drainage Basin Problems and Programs," and it comprises comprehensive treatment of 17 regional basins and 99 individual river watersheds covering the entire country. In each case, investigation projects and construction projects were compiled and recommended under three classifications: (1)

Group A—for immediate investigation or construction; (2) Group B—for deferred construction; and (3) Group C—time of construction indeterminate. The estimated cost of Group A investigation projects is $20,000,000; of Group A construction projects, $1,727,000,000; and of Group B construction projects, $1,024,000,000. Before final completion of some of the larger projects in the next 10 years or more, additional sums amounting to $600,000,000 for A projects and $400,000,000 for B projects are estimated to be required.

The type of projects considered and recommended include:

Bank and coastal erosion control
Domestic and industrial water supply
Drainage
Flood control
Generation of electric power
Irrigation
Navigation
Recreation
Soil conservation and forest development
Waste disposal and pollution abatement
Wild-life conservation

The locations of each of the preceding projects are shown in appropiate symbols on maps of each of the watersheds. The number and distribution of recommended drainage projects primarily for malarial control is surprising.

In regard to the administration and financing of the recommended projects the committee says:

> Neither the plan nor the program rest upon any assumptions as to how the proposed developments should be financed or administered. It is obvious, however, that the effective fulfillment of such a comprehensive water plan is contingent upon the effective solution from time to time of the pressing problems of financial and administrative policy.

Quoting from the Report of the Water Planning Committee in the 1934 Report of the National Resources Board, page 340, on a national water-use policy:

> The weight to be given drainage in the formulation of a water policy probably will depend in part on its economic purpose and value under the following classifications: (*a*) Land reclamation, and (*b*) Mosquito control.

Land reclamation through drainage includes (1) the improvement of land already in farms, and of similar nature; (2) the removal of excess water and alkali resulting from irrigation; and (3) reclamation of marsh or swamp land not previously in farms. The total area in drainage enterprises in the United States by 1930 was 84,408,093 acres. The reclamation of marshes and swamps involved 27 per cent and the

TABLE 8.—DRAINAGE STATISTICS BY STATES FROM FIFTEENTH CENSUS OF THE UNITED STATES, 1930[1]

NORTH ATLANTIC DRAINAGE

New England, New York, Pennsylvania, New Jersey, Delaware: no drainage districts

SOUTH ATLANTIC AND EASTERN GULF DRAINAGE[2]

Drainage prevailingly for reclamation of wet land

State	Total acres	*a* (delinquent), per cent	*b* (unimproved), per cent	*c* (idle), per cent
Virginia	15,042	0.6	59.8	63.1
North Carolina	679,236	14.5	55.0	53.4
South Carolina	208,249	37.0	63.7	60.5
Georgia	84,255	41.1	46.6	41.6
Florida	5,954,934	51.2	86.9	92.4
MISSISSIPPI RIVER DRAINAGE				
Drainage prevailingly for improvement of land in farms				
Ohio	8,165,494	0.3	6.8	4.4
Indiana	10,214,014	0.9	8.3	4.7
Illinois	5,032,682	2.0	5.6	4.6
Iowa	6,137,649	3.4	2.8	1.2
South Dakota	697,758	5.3	5.1	7.4
North Dakota	1,094,142	0.2	1.7	9.4
Nebraska	879,459	1.5	5.2	5.2
Kansas	257,169	0.1	3.4	1.2
Oklahoma	170,158	4.2	16.1	15.3
Drainage prevailingly for reclamation of wet land				
Missouri	3,150,022	30.1	26.7	27.9
Kentucky	585,625	10.0	23.9	38.0
Arkansas	4,631,155	22.0	43.5	43.9
Tennessee	593,560	38.1	51.7	54.6
Mississippi	2,988,496	4.6	34.7	32.6

From National Resources Board report, p. 342, Dec. 1, 1934.

[1] Shows total acres in drainage enterprises, and, successively, percentages of area (*a*) delinquent in drainage taxes, (*b*) unimproved, and (*c*) idle.

[2] Land-drainage enterprises in Mississippi are principally outside this area.

TABLE 8.—DRAINAGE STATISTICS BY STATES FROM FIFTEENTH CENSUS OF THE UNITED STATES, 1930.[1]—(*Continued*)

Drainage prevailingly in connection with irrigation projects

State	Total acres	*a* (delinquent), per cent	*b* (unimproved), per cent	*c* (idle), per cent
Montana........	167,629	4.0	11.2	10.8
Wyoming.......	245,703	8.5	26.0	26.2
Colorado........	366,719	6.5	17.6	19.0

GREAT LAKES AND RED RIVER DRAINAGE

Drainage prevailingly for reclamation of wet land

Michigan.......	9,180,851	3.5	16.5	11.0
Wisconsin.......	892,713	27.0	40.4	42.4
Minnesota......	11,474,683	26.2	35.5	32.6

NORTHWEST PACIFIC DRAINAGE

Drainage projects partly for swamp-land reclamation and partly in connection with irrigation projects

Idaho...........	375,464	3.3	5.5	7.5
Washington.....	367,242	4.8	9.5	9.2
Oregon..........	211,182	33.2	31.7	24.8

SOUTHWEST PACIFIC AND GREAT BASIN DRAINAGE

Drainage prevailingly for reclamation of wet land

California.......	2,233,714	9.4	11.0	16.1
Nevada.........	162,980	4.5	24.5	27.8
Utah...........	156,052	62.9	11.5	39.0

COLORADO RIVER DRAINAGE

Drainage in connection with irrigation projects

Arizona.........	318,931	1.1	30.8	12.3

SOUTHWEST AND WESTERN GULF DRAINAGE

Drainage prevailingly for reclamation of wet land

Texas...........	2,883,356	9.8	30.5	28.3
New Mexico.....	176,292	11.4	16.8	17.5
Louisiana[2].......	3,655,483	4.3	37.9	36.8

---

[1] Shows total acres in drainage enterprises, and, successively, percentages of area (*a*) delinquent in drainage taxes, (*b*) unimproved, and (*c*) idle.

[2] Part of this reclaimed area lies within the Mississippi Basin, but the larger portion is in the Gulf drainage area; the state is therefore listed within the latter area.

improvement of lands already in farms involved 63 per cent of the total area.

Mosquito control included (1) malarial control in the interest of public health, and (2) nuisance abatement, whether for the improvement of land values, the conditions of labor, or the conditions of recreation.

A very good measure of the success or failure of drainage projects in the past and the location of the failures can be had by examining the statistics on tax delinquency. These are presented in Table 8, which was compiled from data collected in the 1930 census. "Idle includes all land not in productive use, such as idle crop land, land in unoccupied farms, woodland, and other unimproved land not intensively used for pasture or farm wood lots. Practically all timber and cut-over lands are classed as idle."

The National Resources Board in 1934 classified all farm lands in the United States from the point of view of productivity as follows:

Grade	Description	Acres
1	Excellent	101,038,000
2	Good	210,935,000
3	Fair	345,872,000
4	Poor	362,559,000
5	Incapable of tillage	881,735,000

The various grades are described as excellent, good, fair, or poor land for the staple crops climatically adapted to the region in which the land is situated. Since a study of available information indicates that almost one-third of the total of Grades 1 and 2 represents drained land, and that about one-half of the Grade 1 farms consists of land in drainage enterprises or land requiring drainage, it is evident that a large proportion of the best agricultural land in the United States is dependent upon drainage as a fundamental requirement.

11. Future Outlook.—Careful examination of the voluminous literature on the subject of water- and land-use planning made available since 1933 reveals nothing in basic conflict with the appraisal presented in the first edition of this book. The chart shown in Fig. 2 is, therefore, reproduced substantially as it appeared in 1928. Several factors will influence the rate at which new land will be reclaimed and put into crop production. Chief among these are (1) trend and rate of population increase, (2) status of foreign demand for domestic products, (3) amount and rate of retirement of lands made submarginal by erosion or inherent unfitness for cultivation, and (4) amount and rate at which more rotation pasture and forage is incorporated into cropping cycles.

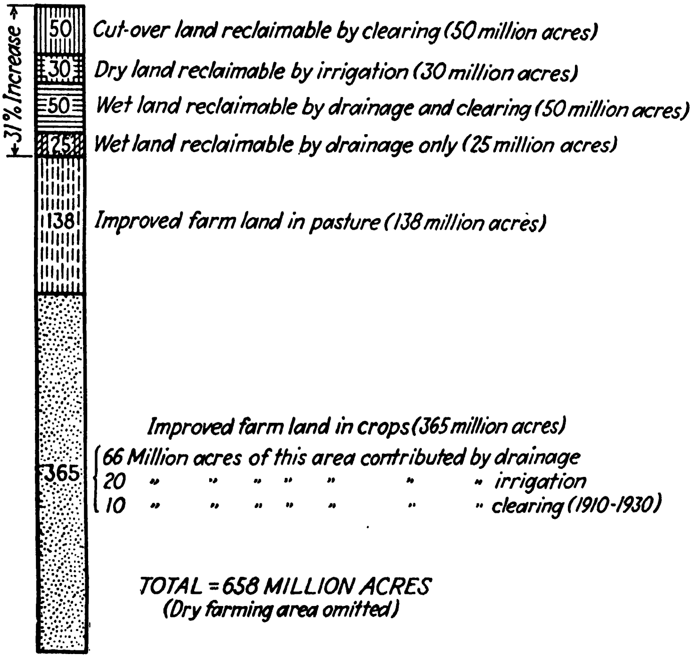

FIG. 2.—Amount of desirable land in the United States now used for cultivated crops and rotation pasture, together with ultimate possible increase by various methods of reclamation.

Most authorities agree that the population of the United States will gradually increase by 15,000,000 or 17,000,000 to 140,000,000 in 1960 and will remain stationary until 1970, after which a gradual decline will set in. To provide for this population increase it is estimated that 30,000,000 additional crop acres will be needed in 1960. It is also estimated that 20,000,000 acres of submarginal land will be withdrawn in the next 15 years and that 5,000,000 acres of present crop land will be transformed to rotation pasture in order better to conserve fertility. No one seems to have the temerity to predict what will happen to foreign trade relations in the next 20 years.

As to where this 55,000,000 acres of new land will come from and how it will be made available, the National Resources Board has this to say:

> In case the yield per acre of our crop land is seriously reduced by continuous cropping without adequate rotation, and erosion takes its toll, and in case foreign demand is fully restored (to former levels), it is probable that by 1960 we will require, in order to take care of our domestic and foreign demand for agricultural products, new crop land of at least the following amounts from the sources stated:
>
> 3,000,000 acres of irrigated land within the range of probable feasible cost
> 10,000,000 acres through drainage
> 10,000,000 acres of new clearing on the better quality of soils now in stumps or trees
> 32,000,000 acres from plowable pasture

It is not made clear just what kind of pasture is considered "plowable," but it seems certain that a large proportion will require rather thorough protection against erosion by terraces or other mechanical means after its vegetal cover is destroyed. This statement would also apply to the 10,000,000 acres of new cleared land.

From the standpoint of the conservation engineer, therefore, it would seem that the best outlook for new construction activities in the next 20 years lies in the field of erosion control (not only on "new" lands but also on numberless fields now in cultivation), whereas the chief activity in drainage and irrigation will be to maintain and improve the works now in existence. It does not follow by any means that the latter activities are less important or less vital to the public welfare than the former.

In formulating an estimate of the present situation, the need for supplemental irrigation and private projects for direct drainage of individual farms, as well as drainage designed for malarial control and other public-health interest, should not be overlooked. Non-agricultural drainage of public and private utilities is also entitled to a place of importance.

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CHAPTER II

MEASURING DISTANCES

The various acreage-adjustment and allotment programs of the past few years have brought into sharp relief the need for a knowledge of surveying instruments and the acquisition of skill in their use. The first step in any kind of planning is the assembling of basic information and its representation in a form for convenient use. Maps, drawn to various scales to suit various purposes, are invaluable aids when locating property boundaries, interior fence lines, farm roads, buildings, wells, drains, etc., and are indispensable in the proper planning of field layouts for various crop rotations. Maps also serve as a convenient means of keeping track of yearly expense outlays on each field, fertilizer applications, crop yields, and many other useful items.

12. Surveying Defined.—No map, chart, or other paper device can be created without first making estimates or field measurements of the physical features which are to be represented. This process of measuring is termed *surveying*, and methods of surveying to correspond with various standards of accuracy have become well established. In practice, surveying is generally considered to involve the measuring, location, and plotting on paper of lines, angles, and contours on the earth's surface, and the computation of areas.

All distances for the purpose of surveys are measured in either a vertical or a horizontal plane. Vertical distances, or differences in elevation, are determined by the use of levels and level rods (or, rarely, by the use of aneroid barometers). Horizontal distances are determined by pacing (for rough work) or by the use of chains, tapes, rules, stadia wires, odometers, and speedometers.

13. Chains.—There are two kinds of chains: the engineer's and Gunter's. The engineer's chain is 100 feet long and is divided into links 1 foot long, each end of the chain being provided with a handle.

The Gunter's chain was devised by Edmund Gunter of England in 1620. It is 66 feet long and is divided into 100 links, each link representing 0.66 foot or 7.92 inches. This chain was adopted for use in the extensive public-land surveys of the United States during the nineteenth century because of its simple relationship to the acre and the mile.

1 Gunter's chain	100 links
1 chain	4 rods
80 chains	1 mile
10 square chains	1 acre

14. Tapes.—There are two kinds of tapes: metallic cloth and steel. Metallic cloth tapes are graduated in either feet and inches or feet and tenths of a foot. They usually come in lengths of 50 feet and are coiled in leather cases from which they are easily unwound and wound. These tapes are useful because of their handiness but are not suited for extended surveys on account of a tendency to stretch.

Steel ribbon tapes (or band chains) are available in a variety of widths, thicknesses, and lengths, with graduations either in feet and inches or in feet and tenths of a foot. In lengths of 50 feet and longer they are obtainable without cases or reels, which are considered an unnecessary expense and bother by chainmen who have mastered the trick of "looping and throwing."

Probably the most satisfactory tape for all-around agricultural surveying is one of the band-chain type, $\frac{5}{16}$ inch wide and 100 feet long, with markings on Babbitt-metal mountings or "bosses" spaced every foot, the last foot at each end being divided into tenths.

15. Chains and Tapes.—The Gunter's chain is now practically superseded by the 100-foot steel tape. The principal reason for this change is that chain measurements are not so accurate as tape measurements, owing to the fact that the chain presents a greater number of wearing surfaces. Each long link is connected to the next long link by a number of small links; each one of these links has two wearing surfaces, so that if each of these many wearing surfaces wears only a very little, the result is an appreciable lengthening of the chain. The handles of the chain have adjusting screws to take up this wear, but as the average farmer has no standard by which to check his chain, the adjusting device is of little value to him. Another more serious drawback to the use of the Gunter's chain is its unhandy unit. Except for the measurement of acres and miles, the 7.92-inch link is unhandy. The measuring device used on the farm has other uses than these—for example, laying out buildings, staking off tile drains, measuring haystacks, etc.

The steel tape, in 100-foot lengths and divided into feet and tenths of a foot, lends itself better to the diversity of uses demanded of it in agricultural surveying.

16. Rules.—Rules are sometimes used to measure short distances. They can be obtained in lengths from a few inches up to 8 or 10 feet and graduated in either feet and inches, feet and tenths of a foot, or both.

17. Stadia.—By having two additional horizontal cross hairs in the telescope of a transit or a level (Fig. 3), the distance a rod is held from the instrument may be determined. This is accomplished by taking rod readings on the upper and lower stadia wires and obtaining the difference between these readings, which is the number of feet intercepted on the rod by them. There is a definite relation between this rod reading and the number of feet the rod is distant from the instrument. Usually, the space between stadia wires is so designed by the instrument maker that a reading giving 1-foot difference on the rod between the stadia wires means that the rod is 100 (plus a constant) feet away. This method is not generally used for agricultural surveying.

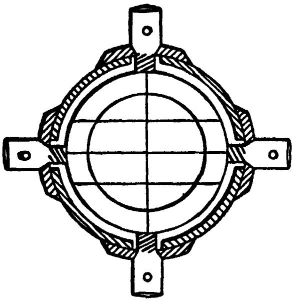

Fig. 3.—Stadia wires.

18. Odometer.—The odometer is an instrument which can be attached to a buggy or wagon and will register the number of revolutions of the wheel. The circumference of the wheel being known, the distance passed over can be computed. If no odometer is at hand, the same result can be accomplished by tying a white rag to the wheel and noting the number of times the wheel revolves. This method, of course, is used only when an approximate distance is wanted.

19. Speedometer.—The speedometer as found on the automobile offers another method of getting approximate distances.

In the measuring of horizontal distances where the work is done by means of the steel tape, something is needed besides just the tape. Three important accessories are: chain pins, range poles, and plumb bobs.

20. Chain Pins.—Chain pins, or *arrows*, as they are sometimes called, are wire pins about 12 inches long with a loop at one end, the other end being pointed. A set consists of 11 pins (Fig. 4). They are used to stick in the ground to mark the end of the tape or chain in measuring distances.

21. Range Poles.—Range poles, or *flags*, as they are sometimes called, are small, round, or many-sided rods, usually 8 feet long, with one end having a pointed shoe (Fig. 5). They are painted alternately white and red, each color being a foot in length. These poles are made of wood or steel. They are used to mark points which must be seen from a distance.

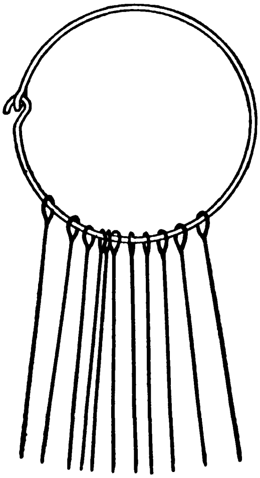

Fig. 4.—Set of chain pins.

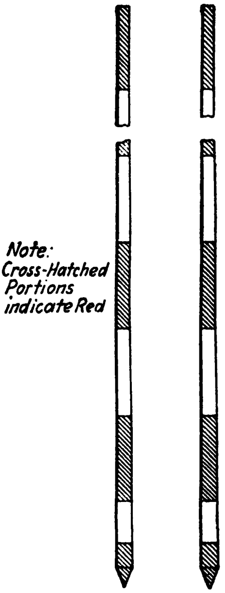

Fig. 5.—Range poles.

22. Plumb Bobs.—Plumb bobs are usually made of brass with a steel point; they are used in getting a point directly above another point below, or *vice versa* (Fig. 6).

23. Pace.—Where the approximate distance between two points close together is required, the common method of obtaining it is by pacing or stepping off.

In pacing the distance, the length of the pace is usually assumed to be 3 feet. Each person should determine the length of his pace, both of his average steps and of his assumed steps, *i.e.*, the step he assumes when pacing off distances.

The method of determining the length of step is to lay off a straight and level course 300 feet long. Walk over the course a sufficient number of times, keeping count of the number of steps taken each time to get a good average. Then, by dividing the average number of steps into 300 feet, the average length of the pace is determined.

24. Use of Steel Tape.—In measuring distances of appreciable length with the steel tape, the following equipment is necessary: one 100-foot steel tape graduated in feet and tenths of a foot, one set of chain pins, two range poles, and a plumb bob.

In measuring the distance between two points, first place the range poles at the points to be chained between, provided that the points are not already marked so that they can be seen at a distance. The tape is then undone and carefully gone over to see where the 0 end of the tape starts and likewise where the 100-foot mark ends.

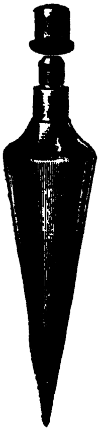

Fig. 6.—Plumb bob.

Some tapes have both these points at the very ends of the tape; others have them a short distance in from each end of the tape; still others have them 1 foot or more from each end, with a graduated foot or more intervening between the end of the tape and the 0 or 100-foot mark of the tape.

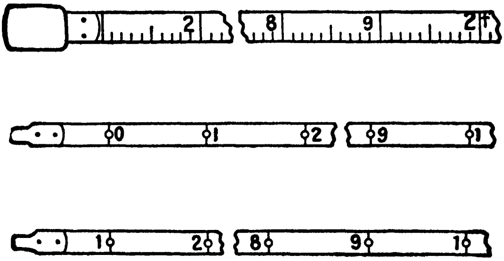

Fig. 7.—Methods of marking ends of steel tapes.

Figure 7 shows common endings of tapes. Failure to observe where these points are will lead to mistakes.

Next, place a chaining pin at the starting point; the other 10 pins should be given to the head chainman. (The chainman who goes ahead is called the *head chainman*, while the one who follows is called the *rear chainman.*) The rear chainman holds the 100-foot mark on the starting point, while the head chainman goes forward toward the objective point with the 0 end of the tape. When the tape becomes tight, the rear chainman should put the head chainman on line by sighting on the forward range pole. When he is on line, the tape is straightened out, drawn tight, and held level. It is customary to exert approximately a 15-pound pull on the tape. When the rear chainman has his end of the tape on the mark and is ready for the head chainman to mark the 100 feet of distance, he will call, "Stick." The head chainman then sticks a chain pin in the ground at the 0 mark of the tape, and calls, "Stuck." The rear chainman then drops the tape, pulls up the chain pin, and walks to the place where the head chainman has just placed the pin; the head chainman goes ahead pulling the tape after him. When the end of the tape is almost to the pin, the rear chainman calls, "Chain," thus causing the head chainman to stop. The rear chainman puts the head chainman on line again, and the tape is straightened out, pulled tight, and leveled as before. These operations are repeated until the head chainman has no more pins (or the point to be chained is reached). The rear chainman then gives him the 10 he has, the one remaining in the ground to mark the place where the tape stopped, making 11 in all. As one was placed in the ground to start with, the distance passed over, or measured, is 10 tape lengths, or 1,000 feet.

Whenever pins are passed between two men, each man should verify the number of pins handed him. This is a necessary precaution to eliminate mistakes and should not be taken as a reflection on one's ability to count.

To determine the number of hundred feet chained, when the point to be chained to is reached, the difference between the number of pins which the head chainman has when finished and 10 plus any 1,000 feet that have been made will give it. The number of pins which the head chainman has should be taken rather than the number the rear chainman has, because he may have forgotten to pick up one or more.

To get the number of feet and parts of a foot, less than a hundred, it is necessary that one of the chainmen hold the tape on a pin at a foot mark, which will allow the graduations of the 0 end of the tape to come to the point chained to. The number of tenths of a foot is read, and the number of hundredths of a foot estimated from the 0 or 100-foot end of the tape. This amount is then subtracted from the value of the foot mark which the other chainman is holding on the pin. For example, if one chainman reads 0.75 from the 0 end of the tape and the other chainman is holding on 42, then the distance is 42 minus 0.75, or 41.25 feet.

In measuring distances on uneven ground, it is absolutely necessary that the tape be held horizontally and a plumb bob used to hold the tape over the point measured from or to in order to locate the point on the ground under the tape. *Beginners in surveying are likely to believe this unnecessary and not pay any particular attention to it until they are unable to check.* In going up and down very steep inclines, it is necessary to *break chain;* that is, if a 100-foot tape is being used, measure only 50 or 25 feet at a time, because it would be impossible to measure a longer distance and still hold the tape level. Care should be taken, when it is necessary to break chain, not to get the pins mixed up and lose count of the number of hundred feet measured. Possibly, the best way to eliminate any error from this cause is for the rear chainman to come forward and hold the same place on the tape which the head chainman held and use one pin over and over again until a 100-foot length is measured.

The distance between two points should be measured twice, once in each direction, in order to have a check.

25. Degree of Accuracy.—In measuring distances with a tape, the degree of accuracy required in agricultural work is that the distances obtained by the two chainings should not differ more than 1 foot for every 5,000 feet chained.

To find whether the error for the distance measured is within this limit, proceed as follows: Get the difference between the two measurements and find the average distance, after which determine the distance at this rate that would be measured in order to miss it 1 foot. This is called the *ratio of error.*

Example.—Suppose that the distance obtained between the two points were 984.65 and 984.39—a difference of 984.65 minus 984.39 or 0.26. The correct distance is the average of the two or 984.52. The ratio of error is $0.26:984.52::1:x$.

$$x = 3{,}786$$

Ratio of error is 1:3,786.

Or, in other words, in chaining this distance, a foot every 3,786 feet was lost, and the degree of accuracy called for was that the loss should not be greater than 1 foot in 5,000 feet. Here the error was too great; hence, the work must be done over.

26. Common Errors in Measurement.—The following are common sources of error in getting the true distance between two points:

Tape not pulled tight enough, too much sag
Plumb bob not used in measuring on a slope
Pins not carefully placed at proper marks of tape
Mistake in counting pins
Mistake in determining the number of feet less than 100
Not getting tape always on line

27. Units of Measure.—The units of measure used almost altogether for surveying are the foot and tenths of a foot. Inches are not used at all. The following tables are given to assist the student in transposing values from one unit to another:

Linear Measure

United States

12	inches	1 foot
3	feet	1 yard
16½	feet	1 rod
320	rods	1 mile
5,280	feet	1 mile
1,760	yards	1 mile

Spanish

Vara of Castile	32.8748	inches
Vara of California	33.372	inches
Legua	5,000	varas
Legua	2.6335	miles
Fanegada	1.5871	acres
Fanegada	69,134.08	square feet

Metric

10 millimeters	1 centimeter
10 centimeters	1 decimeter
10 decimeters	1 meter
1,000 meters	1 kilometer

Gunter's Chain

1 chain	100 links
1 chain	4 rods
80 chains	1 mile
10 square chains	1 acre

Conversion Table

1 chain	66	feet
1 chain	20.1168	meters
1 link	7.92	inches
1 link	0.66	feet
1 foot	0.3048	meters
1 inch	2.54	centimeters
1 meter	3.28023	feet
1 centimeter	0.3937	inches

TABLE 9.—TENTHS AND HUNDREDTHS OF A FOOT TO INCHES

This table is not closer than ⅛ inch. It is valuable for changing feet and tenths to feet and inches or *vice versa*. This is useful in tile drainage.

		Hundredths of a foot										
		0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	
Tenths of a foot	0	0	⅛	¼	⅜	½	⅝	¾	⅞	1	1⅛	0
	0.1	1¼	1⅜	1½	1⅝	1⅝	1¾	1⅞	2	2⅛	2¼	0.1
	0.2	2⅜	2½	2⅝	2¾	2⅞	3	3⅛	3¼	3⅜	3½	0.2
	0.3	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜	4½	4⅝	4¾	0.3
	0.4	4⅞	5	5	5⅛	5¼	5⅜	5½	5⅝	5¾	5⅞	0.4
	0.5	6	6⅛	6¼	6⅜	6½	6⅝	6¾	6⅞	7	7⅛	0.5
	0.6	7¼	7⅜	7½	7⅝	7⅝	7¾	7⅞	8	8⅛	8¼	0.6
	0.7	8⅜	8½	8⅝	8¾	8⅞	9	9⅛	9¼	9⅜	9½	0.7
	0.8	9⅝	9¾	9⅞	10	10⅛	10¼	10⅜	10½	10½	10¾	0.8
	0.9	10⅞	11	11	11⅛	11¼	11⅜	11½	11⅝	11¾	11⅞	0.9

Surface Measure

United States

144	square inches	1 square foot
9	square feet	1 square yard
30¼	square yards	1 square rod
4,840	square yards	1 acre
43,560	square feet	
160	square rods	

Metric

100	square millimeters	1 square centimeter
1,000	square centimeters	1 square decimeter
100	square decimeters	1 square meter
10,000	square meters	1 hectare

Conversion Table

10 square chains	1	acre
1 acre	4,046.87	square meters
1 square meter	10.7639	square feet
1 hectare	2.47104	acres

28. Care and Repair of Steel Tapes.—In unwinding and using a steel tape, care should be taken not to get any kinks in it. If kinks are not taken out before pulling the tape tight, they will result in a broken tape. Allowing railroad trains, tractors, and heavily loaded wagons to run over the tape will also cause it to break.

Should a tape get broken, it can be mended either by soldering a little steel sleeve over the broken part (Fig. 8) or by using another type of sleeve which is clamped to the broken ends by means of screws (Fig. 9). The authors have found this latter type of mending much more satisfactory. Either of these types can be obtained from practically any dealer in surveying equipment.

Steel tapes of the better grade are rust resisting, but where they are not to be used for some time, it would be well to apply a coat of grease or oil before storing. With reasonable use and care the steel tape should last a long time.

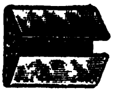

FIG. 8.—Tape-mending sleeve.

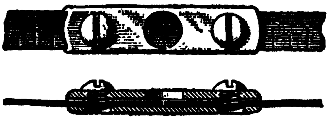

FIG. 9.—Tape-mending device.

Problems

1. If the distance between two points is chained twice, and the distances found are 28,095.7 and 28,096.5, what is the ratio of error? Is it within the limits given in Art. 25?

2. If the distance between the two points is chained twice, and the distances found are 8,847.5 and 8,846.3, what is the ratio of error? Is it within the limits given in Art. 25?

3. How many feet and inches are equivalent to 182.71 feet?

4. How many feet and inches are equivalent to 29.05 feet?

5. How many feet, tenths, and hundredths of a foot are equivalent to 17 feet 4½ inches?

6. How many feet, tenths, and hundredths of a foot are equivalent to 62 feet 8¾ inches?

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CHAPTER III

SURVEYING WITH STEEL TAPE

It is often necessary, in the course of farm operations, to lay out a building or determine the size of a field without the aid of a compass or transit to measure the angles. It is, therefore, desirable that methods of doing this with a tape should be understood.

DETERMINING THE SIZE OF A GIVEN ANGLE

29. Sine Method.—Refer to Fig. 10. Let angle *BAC* be the angle to be measured. Set the range poles at *B* and *C*, with the tape measure out from *A* on line *AB* some even distance, say, 40, 50, 60, 80, or 100 feet. Locate this point as *D* with a chain pin. Do the same thing on line *AC*, using the same distance and thus locate point *E*; mark with a chain pin. Now, find the exact distance *DE* in feet and tenths of a foot. The size of angle *BAC* can be found by the following computations: Take half the distance *DE*; divide it by the distance *AD*; look up this value in a table of natural sines (see Table 45 in the appendix) and find the angle it represents. Twice this angle will be the angle *BAC*.

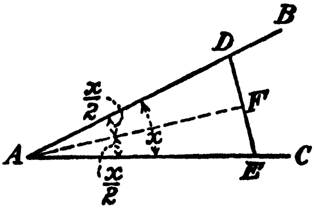

Fig. 10.—Sine method.

Proof.—*AF* divides the angle *BAC* into equal parts, and *AFD* is a right angle. Why? Let the angle *BAC* be represented by *X*. Then sine $x/2$ equals *DF* over *AD*. Determine the value of $x/2$ and twice that would be *X*.

Caution.—Do not multiply sine $x/2$ by 2 and then look up value of angle and expect to get *X*.

30. Large Angles.—Should the angle which is to be measured be greater than 90°, it would be better to measure the angle which is less than 180° or, in some cases, 360°. In Fig. 11 is

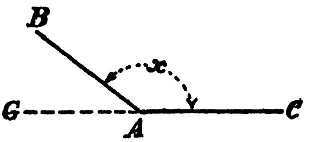

Fig. 11.—Large angles.

shown a case when, instead of measuring the angle *BAC*, it would be better to extend the line *CA* to some point *G* and measure the angle *GAB*. When *GAB* is found, subtract it from 180°, and this will give *BAC*.

31. Tangent Method. *First Method.*—Refer to Fig. 12. Let angle *CAB* be the angle to be measured. Set up range poles at *B* and *C* Measure some even distance, say, 40, 50, 60, or 100 feet on line *AC* from *A*. Let this point be *E*. Erect a right angle at *E* on line *AC*. Find where the line perpendicular to *AC* and through *E* intersects *AB*, and let that point be *D*. Measure the length of *ED*. Now, the angle *BAC* can be found by the following computations: Divide the length of *DE* by the length of *AE*; the result will be the natural tangent of angle *BAC*.

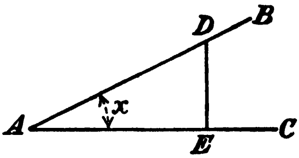

Fig. 12.—Tangent method.

Proof.—The natural tangent of *BAC* equals *DE* over *AE*.

Second Method.—Refer to Fig. 10. Proceed as in Art. 29 and get the lengths of *AE* and *AD*, also *DE*. Then locate *F* on the ground and mark it with a chain pin. Measure *AF*, getting its length in feet and tenths of a foot. Now the angle can be obtained by the following computations: Divide the length of *DF* by the length *AF*. Find the angle of which this value is the natural tangent. Twice this angle will be the angle *BAC*. The same caution given in Art. 29 applies here, also.

Choice of Method.—The first method can be used on small angles, while the second is better for larger angles. When a check is desired, the second method is best, as the sine method can also be applied to the values obtained.

Large Angles.—The method given in Art. 30 regarding the values of angles approaching or greater than 180° also applies here.

LAYING OUT RIGHT ANGLES

32. Three-four-five Method.—Refer to Fig. 13. Let line *AB* be the line on which the right angle is to be laid off, and point *C* the point on that line where the angle is made. Have one man hold the 0 end of the tape and the 60-foot mark at this point *C*. Have another man hold the 40-foot mark on the line *AB* at some point *E*. The third man can sight him from point *A*, so he will be on line with *B*. This man at *E*, then, will be

20 feet from *C*. The third man then takes the 15-foot mark and goes to some point *D*, which will be found when the tape is pulled tight along lines *DE* and *DC*. Then a line through *CD* is perpendicular to *AB*, and the angle *ACF* is a right angle.

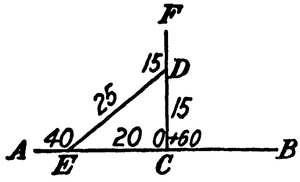

Fig. 13.—Three-four-five method.

A variation of the three-four-five method is shown in Fig. 14. In this method the first man at *C* holds the 0- and 70-foot marks on the tape, the second man at *E* holds the 20- and 25-foot marks, and the third man at *D* holds the 50- and 55-foot marks. Each man then holds the two foot marks mentioned exactly one above the other at the respective points, thus making loops five feet long at *E* and *D*.

Proof.—Twenty squared plus fifteen squared equals twenty-five squared. This is called the *three-four-five method*, because any multiples of three, four, and five can be used.

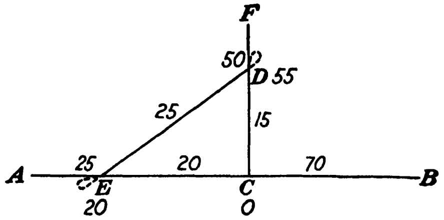

Fig. 14.—Alternate three-four-five method.

33. Chord Method. *First Method.*—Refer to Fig. 15. Let line *AB* be a straight line, and *C* be the point on that line at which a right angle is to be erected. Set up range poles at *A*

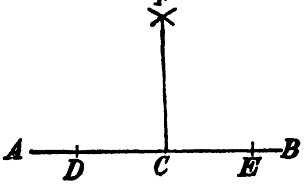

Fig. 15.—Chord method. *First method.*

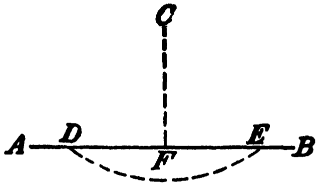

Fig. 16.—Chord method. *Second method.*

and *B*. Measure off some distance from *C* and locate any point *D* on line *AB*, then measure off the same distance on the other side of *C* and locate point *E* on the line *AB*. Using the steel tape, take a radius somewhat greater than *EC*, and with

E as a center describe, with a chain pin, an arc. With the same radius and *D* as a center, describe another arc. These two arcs will intersect at some point *F*. A line through *C* and *F* will be perpendicular to *AB*, and *ACF*, as well as *BCF*, will be a right angle. Why?

Second Method.—Refer to Fig. 16. Let *AB* be a straight line and point *C* be some point off *AB*, through which a line perpendicular to *AB* is to be passed. Set up range poles at *A* and *B*. With one end of the steel tape at *C* used as a center and a radius greater than *CF*, describe with a chain pin an arc which will cut the line *AB* at two points *D* and *E*. A man standing at *A* can sight along *AB* and tell when the pin intersects this line. Find half the distance between *D* and *E*, which will be some point *F*. A line through *F* and *C* will be perpendicular to *AB*, and the angles *AFC* and *BFC* will be right angles. Why?

34. Semicircle Method.—Refer to Fig. 17. Let line *AB* be a straight line, and point *C* be some point on that line at which a right angle is to be erected. Set range poles up at *A* and *B*. Take some point *F* off the line *AB*. With one end of the steel tape at *F* and a radius *FC*, describe a semicircle which, at one end, shall cut *AB* at some point *D*. Pass a line through *D* and *F* until it intersects the semicircle at some point *E*. A man at *D* can sight through *F* and locate a pin held on the semicircle. Then a line passed through *C* and *E* is perpendicular to *AB*, and the angles *ACE* and *BCE* are right angles. Why?

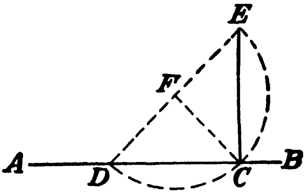

Fig. 17.—Semicircle method.

LAYING OUT ANGLES OTHER THAN A RIGHT ANGLE

35. Sine Method.—To use this method, do in reverse order what was done in Art. 29. That is, divide by two the angle to be laid out and find the natural sine of that angle. Refer to Fig. 10. Select the length *AD* and *AE*. Multiply this distance by the sine of the angle, and the result will be *DF* or *EF*. Twice the distance will be *DE*. Now, with a pin set at *A*, the point at which the angle is made, measure out on *AC* or *AB*, if the direction of either of these lines is given, the distance selected. Set a pin at this point. Then, with the zero end of the tape at *A* and one man holding on the number of feet equal to *AD* or *AE*, plus *DE*, and stationed at *E*, let another man holding on the number of feet on the tape equal to *AD* or *AE* draw the tape so that it is tight on *E* and on *A*; the point at which he finds himself will be *D*. Place a pin here, and the given angle is laid out. Prove it.

36. Tangent Method.—This can be done by working backward the method shown in Art. 31. The student should be able to figure this out himself after having studied the method given in Art. 35.

37. Practical Applications.—The ability to lay off all kinds of angles with the tape alone will be found very useful, particularly in the case of the right angle, as it can be used for many different farm purposes.

The laying out of a building site is a very frequent necessity on the farm. When it is desired to have the building "square with the world," and nothing near is in that condition to which the building can be made parallel, it will be necessary to have an instrument with a compass. But under all other circumstances, the foundation can be easily and quickly laid out with nothing but a tape. Suppose that it is desired to lay off a building of the size and shape shown in Fig. 17*A*. Suppose that one side *AB* was given, and the corner *D* located; then *C* could be located by measuring 100 feet from *D* on line *AB*. Next, erect a perpendicular by the three-four-five method or the chord method at points *C* and *D*. Measure up on these perpendiculars 50 feet and set pins which will locate points *E* and *F*. Now, measure the diagonals *DF* and *CE* on this rectangle; if they are equal, this part of the building is all right. Then measure on line *EF* 20 feet from *E*; this will locate *J*; 20 feet farther along this line will locate *I*. Erect perpendiculars at *I* and *J* and measure up 10 feet on each line, which will locate *G* and *H*. Measure the diagonals *GJ* and *IH*. If equal, this part of the building is all right. The building is now laid out, as all the corners are located. No matter how complicated a building may be, it can be laid out by this method, if it is first divided into squares and rectangles. This will locate the exact corners of the building; the mason, however will have to set up some batter boards,

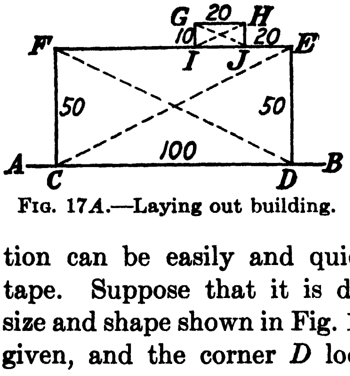

FIG. 17*A*.—Laying out building.

and to do this it is desirable to use a level. The method of setting these batter boards is explained in Art. 83.

Parallel Lines.—One line parallel to another can be laid off as mentioned above in laying off a building. The lines should be checked the same way.

Problems

7. Refer to Fig. 10. If *AD* and *AE* are 63 and *DE* is 57 feet, what is the size of angle *DAE*?

8. Refer to Fig. 10. If *AD* and *AE* are 75 and *DE* is 102 feet, what is the size of angle *DAE*?

9. Refer to Fig. 11. If the angle *GAB* is 54°23′, what is the size of *BAC*?

10. Refer to Fig. 11. If the angle *BAG* is 49°18′, what is the size of *BAC*?

11. Refer to Fig. 12. If *AE* is 40 and *DE* is 17.5 feet, what is the size of angle *DAE*?

12. Refer to Fig. 12. If *AE* is 40 and *DE* is 32.4 feet, what is the size of *DAE*?

13. Refer to Fig. 12. If angle *DAE* is 40°15′ and *AE* is 50 feet, what will be the length of *DE*?

14. Refer to Fig. 12. If the angle *DAE* is 29°32′, and *AE* is 60 feet, what will be the length of *DE*?

15. Refer to Fig. 10. If the angle *DAE* is 46°10′ and *AE* is 50 feet, what is the length of *DE*?

16. Refer to Fig. 10. If the angle *DAE* is 64°20′ and *AE* is 40 feet, what is the length of *DE*?

17. Refer to Fig. 10. If *AD* and *AE* are the same length, *AF* is 39.2 feet, and *DE* is 19.4 feet, what is the size of the angle *DAE*?

18. Refer to Fig. 10. If *AD* and *AE* are equal, *AF* is 44.6 feet, and *DE* is 14.3 feet, what is the size of angle *DAE*?

19. Refer to Fig. 10. If the angle *DAE* is 45°10′, *AD* is equal to 40 feet, and *AE* is equal to 40 feet, what is the length of *AF*?

CHAPTER IV

LEVELS AND LEVEL RODS

The farm jobs that can be accomplished by the use of a level, rod, and 100-foot steel tape include: leveling the foundation and laying off right angles for a building; setting a septic tank at proper depth relative to basement; running grades for tile lines, small ditches, and sanitary sewers; determining possibilities of drainage outlets; running terraces and strip-farming contours; and lining up fences.

38. Level Surface.—A level surface is perpendicular to a line made by a plumb bob at any point on the surface of the earth. As gravity is the force acting on the plumb bob and the tendency of gravity is to draw toward the center of the earth, although it does not at all times draw toward the exact center, then a level surface is a curved surface. Since, however, the angle of curvature of the earth's surface is small, this fact is disregarded, and for practical purposes a level surface is not considered to be a curved surface.

39. Level Bubble Tubes.—In most forms of levels, instead of depending on a plumb bob to give a level surface, a level bubble tube is used. This bubble tube is made of a glass curved longitudinally and partly filled with alcohol or ether, just enough being left out to insure a good-sized bubble. If the curve in this tube is made with a short radius, a slowly moving bubble results; if made with a long radius, a sensitive bubble results. The bubble tube has a graduated scale on top in order to assist in getting the bubble in the true center and thus in a level condition. Both ends of the bubble should be equidistant from the center, to obtain a level condition. A line tangent to the center of the bubble will be level.

40. Levels.—A level is an instrument used in surveying to get a line of sight that is level. It is used to obtain differences in elevations.

There are several kinds of levels: homemade, hand, wye, dumpy, architect, drainage, and farm.

41. Homemade Levels.—There are a number of homemade levels which are suitable for agricultural uses. A few of them are triangular wooden, rectangular wooden, iron pipe, garden hose, and carpenter's.

42. Wooden homemade levels are made in three forms, two of which are made in the form of a triangle, one using a carpenter's level, as shown in Fig. 18, and the other a plumb bob, as shown in Fig. 19; of these two forms, the carpenter's level is more desirable, because the bubble of this level acts more quickly than the plumb bob, and therefore, a saving of time is effected. The main objection to these two levels is that the board across the bottom connecting the two legs, if placed as shown, will not straddle a high place but will "ride" it. The board could, however, be placed higher to overcome, to a certain extent, this objection.

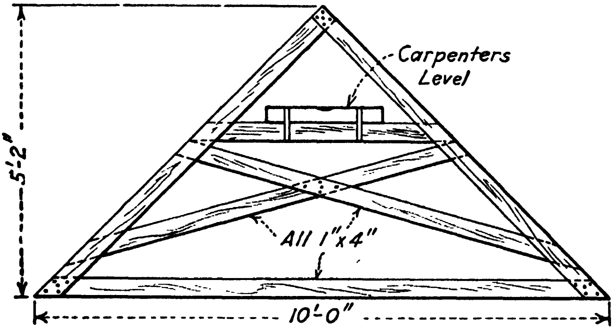

Fig. 18.—Triangular homemade level using carpenter's level.

The rectangular wooden homemade level as shown in Fig. 20 is the most popular of the three types of homemade wooden levels.

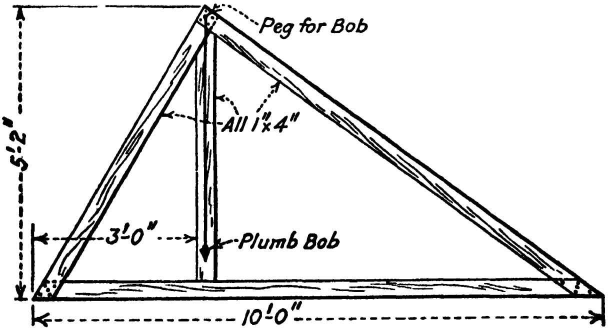

Fig. 19.—Triangular homemade level using plumb bob.

It can easily be made by following the sizes of lumber and dimensions given in the illustration.

After the homemade level is constructed, it should be tested out as follows to see if it is true: Set it upon two points which the level shows to be level; then change ends, *i.e.*, place one leg where the other one was and the other where the first one was. If the bubble, or plumb bob, is still level, the level is correct; if, on the other hand, it does not show level and is, therefore, out of adjustment, adjust for half the error or amount it is out of true by putting something under one end of the carpenter's level (slip a thin piece of board or cardboard under one end of level) and for the other half of the error slip a piece of board under one of the legs; repeat until adjusted.

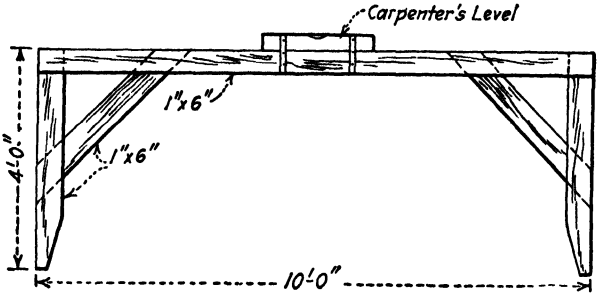

Fig. 20.—Rectangular homemade level using carpenter's level.

The above homemade levels are not used to any extent except to run terraces, irrigation ditches, rice levees, and to level land for irrigation.

43. An iron-pipe homemade level is shown in Fig. 21. This is made of ½-inch galvanized iron pipe. Two glass tubes are inserted in the two elbows, and the top filled with water. A line of sight passing along the water level in each glass is level. It can be seen that this level is crude and can be used only for rough work. It is possible, however, to do some leveling with it, if a very accurate difference in elevation is not needed. A homemade level rod is also shown in the illustration.

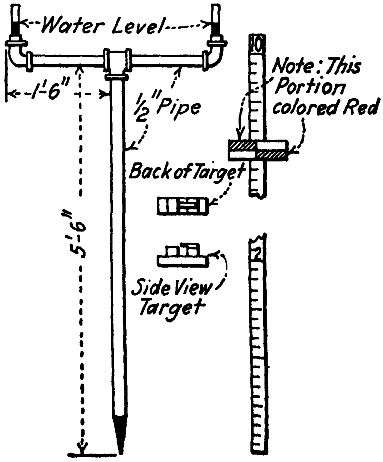

Fig. 21.—Iron pipe homemade level with rod.

44. The garden-hose level shown in Fig. 22 is a simple homemade level developed by Jeffery.[1] It consists of an ordinary

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[1] Jeffery: "Land Drainage."

½-inch garden hose, 60 feet long, and two 12-inch glass water gages such as are used on a steam boiler. These gages are fastened in the ends of the garden hose by means of wire or hose clamps. The hose is filled with water to a point where it will show in the glasses. The water should be clear and free from oil or other foreign materials. Care should be exercised in getting all the air out of the hose after the water has been put in. This can be done by raising one end 5 or 6 feet higher than the other; then, starting at the lower end, raise the hose 3 or 4 feet high until the other end is reached. The level can be tested by comparing the height of water in the two glass tubes. Air in the hose with the water will cause the level to be inaccurate. The principal advantage of this homemade level over others is that on account of its being longer it will give accurate results in less time. It also lends itself to a wider application than most of the others.

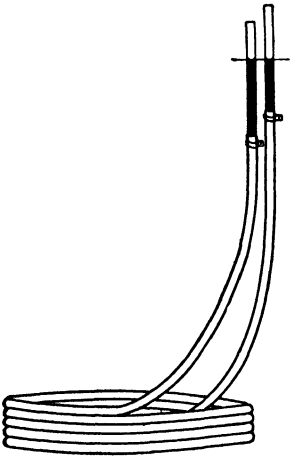


FIG. 22.—Garden hose level.

45. A carpenter's level can be fitted with two sights, so that the user by sighting along the top of the level will obtain a level line of sight (Fig. 23). Homemade tripods can be made upon which to place this level when used for field purposes.

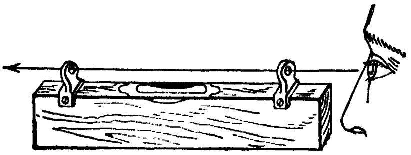


FIG. 23.—Carpenter's level with sights.

46. Hand Level.—The Locke hand level (Fig. 24) consists of a small bubble tube, mounted on top of a telescope which is held in the hand. In looking through the telescope, one half of the vision is given to a reflection of the level bubble, while the other half is given to viewing the rod. The level is held in

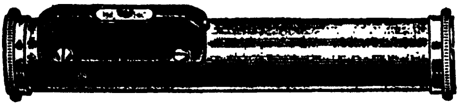


FIG. 24.—Hand level.

the hand, and when the bubble shows level, the reading of the rod is made. This level is not used in agricultural surveying. It is used for preliminary work in locating railroads, highways, etc.

47. Wye Level.—The wye level (Fig. 25) consists of a telescope with the level bubble attached, which is set in two bearings or wyes located at the upper ends of a Y. From this method of attaching the telescope to the rest of the instrument it derives its name. The telescope is clamped in these bearings by means of clips, which can easily be opened to remove it. The level is provided with three or four leveling screws. The main feature of the level is that the telescope can easily be removed from the wyes for adjustment. It is, however, the most expensive of the common levels.

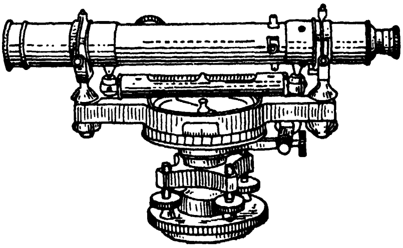


Fig. 25.—Wye level.

48. Dumpy Level.—The dumpy level (Fig. 26) consists of a telescope with a bubble tube attached, all rigidly fixed to the rest of the instrument. It, therefore, differs from the wye level in that the telescope cannot easily be removed. It may have three or four leveling screws. The dumpy level, as a rule, is cheaper, has fewer parts, and is not so easy to get out of adjustment as the wye level. It is considered by some to be harder to adjust than the wye level, but the difference, if any, is slight. The dumpy level is rapidly coming into favor, particularly for agricultural surveying.

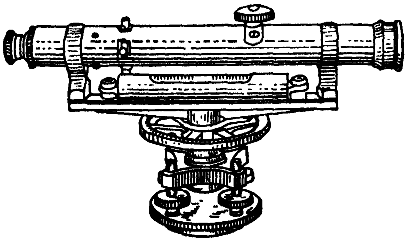


Fig. 26.—Dumpy level.

49. Architect's Level.—The architect's level is a special form of either the dumpy or wye level, differing from either only in that it has some additional attachments which do not come as regular equipment with the ordinary levels. It is provided with means of using a plumb bob to center the instrument over points; it has a horizontal circle for measuring horizontal angles; it may be provided with a compass, and, further, it may be so arranged that the telescope can be moved in a vertical plane for running lines. This level is to be desired for farm uses, as a farmer needs a level which can be employed for reading angles in a horizontal plane as well as finding differences in elevation.

50. Drainage Level.—The drainage level is a special form of wye or dumpy level. It resembles very closely the Architect's level, about the only difference being in the name. Most drainage levels have a plumb bob attachment as well as a horizontal circle for reading angles.

51. Farm Level.—The farm level is a special inexpensive instrument designed and built to handle the farmer's surveying problems. It is of the dumpy type, with a horizontal circle, and a means of using the plumb bob. The greatest asset of these levels is their price. They usually sell for from $20 to $25. There are two on the market: the Bostrom & Brady (Fig. 27), which is manufactured by the Bostrom & Brady Manufacturing Company of Atlanta, Ga., and the Favorite farm level (Fig. 28), manufactured by the Keuffer & Esser Company, New York, N. Y.

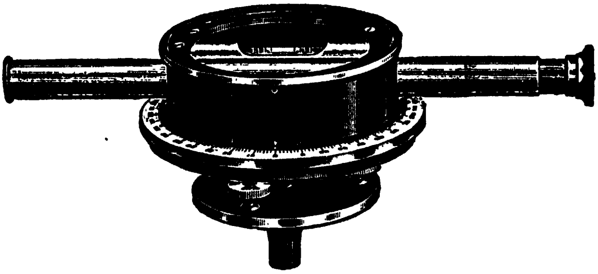


FIG. 27.—Bostrom and Brady farm level.

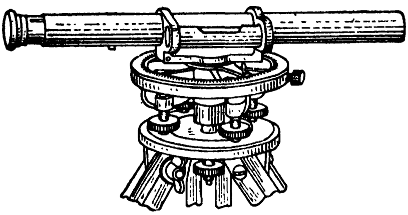


FIG. 28.—Favorite farm level.

The price of these levels includes, besides the level and tripod, a level rod. This rod is graduated in feet and inches rather than feet and tenths of a foot, as the regular level rod.

These farm levels, when properly taken care of and rightly used, will prove satisfactory for average farm uses. County agricultural agents use them to a considerable extent in laying off terraces and for tile-drainage surveys.

Where a better and more expensive level than this type is wanted for farm work, the dumpy architect's level will be very satisfactory.

52. Parts of a Level.—Refer to Figs. 29 and 30. The telescope is a round metal tube which contains the lenses, cross hairs, and other necessary parts for sighting.

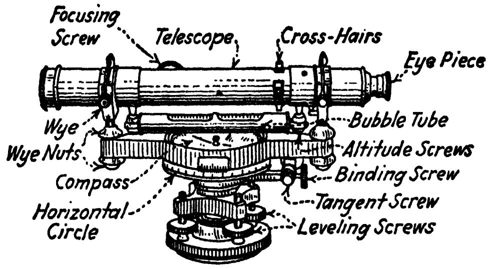


FIG. 29.—Parts of wye level.

The *cross hairs* are usually made of fine platinum wire or a strand from a spider's web; one hair is placed vertical, and one or more horizontal. The horizontal and vertical cross hairs intersect at the center of the field of view. The vertical cross hair is used to give a true vertical direction, and the horizontal cross hair is used to give a true horizontal direction and also give the place on the leveling rod to make the reading.

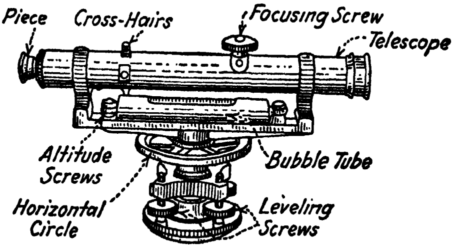


FIG. 30.—Parts of dumpy level.

The *eyepiece* is at the small end of the telescope. This piece can be focused on the cross hairs by lengthening or shortening the telescope. Some instruments, instead of pulling out or pushing in the eyepiece, use a twisting motion. When the eyepiece is properly set, the cross hairs appear black.

The *focusing screw* is a thumbscrew located on and near the large end of the telescope and is used for focusing on distant objects.

The *sunshade* is a metal cylinder which goes over the larger end of the telescope to keep the sun out.

The *line of collimation* or line of sight is the imaginary line that the eye follows in looking through the telescope.

The *bubble tube* is the tube which is placed under or above the telescope and which contains the level bubble.

The *altitude screws* are the screws at the end of the bubble tube to raise or lower the bubble in adjusting the level.

The *azimuth screws* are the screws at the side of the bubble tube to move it to one side or the other in adjusting the level.

The *wyes* are the two supports in which the telescope rests on the wye level.

The *wye nuts* are the nuts at the bottom of the wyes and are used in adjusting the level.

The *leveling screws* may be either three or four in number, are below the telescope bubble, and are used to level the instrument.

The *binding screw* is found on the level just above the leveling screws and is used to hold the telescope rigid in any one position in order to take a reading.

The *tangent screw* is attached to the binding screw and is used to bring the vertical cross hairs directly on line with the distant object after the binding screw has clamped the telescope in approximate position.

The *vertical axis* is a vertical line passing through the center of gravity of the instrument.

The *tripod* is the stand upon which the level is placed.

53. Leveling Up a Level.—When not in use, the level is in two parts—the level proper, which is kept in a hardwood case, and the tripod. When the instrument is to be used, the part in the case is taken out, the metal dust cover over one end of the telescope is removed, and the metal sunshade is put on in its place. The level is then screwed on the tripod.

In setting the level up for making readings, spread the tripod legs apart far enough to insure stability and yet not have it so low that it will be difficult to look through. Place the legs so that the level is approximately in a level position. Then press each leg firmly into the ground. Next, turn the telescope so that it is over two opposite leveling screws. Turn one screw up and the other down at the same time, until the bubble comes to the center. Then turn the telescope around until it stands over the other two leveling screws. (This is, of course, provided that it is a level with four leveling screws. If it has three, turn it so that the telescope is over the remaining one.) Turn the screws the same as before until the bubble shows level. Repeat the same operation as before, having the telescope over the first two leveling screws, and, leveling, continue until the level bubble shows level any way the telescope is turned. Be careful to have each leveling screw up snug against the leveling plate so that the telescope cannot be rocked back and forth; but do not get the screws too tight. They should be just tight enough to turn easily. Injury to the instrument may result from jamming them too tight against the plate.

After the instrument is level, adjust the eyepiece until the cross hairs stand out clear and distinct.

When the level is in a level condition, it is ready for use in reading the rod. To do this, turn the telescope until it is in line with the level rod—this position can be obtained by sighting over the top of the telescope. Next, focus on the rod by means of the focusing screw. When the instrument is in proper focus, the eye can be moved up and down in front of the eyepiece, and the cross hairs will not appear to move. The rod can now be read at the intersection of the middle horizontal cross hair with the rod.

54. Level Rods.—The level rod is used with the level to obtain the distance that the line of sight is above the surface, or the point on which the rod is held.

There are a number of different kinds of level rods, the principal ones used for farm surveying being the Philadelphia, architect's, and ribbon rods.

55. Philadelphia Rod.—The Philadelphia rod (Fig. 31) consists of two pieces, usually 6½ or 7 feet long. These two pieces slide one on the other. The front of one piece and the front and back of the other are painted white and graduated with wide black lines, in feet, tenths, and hundredths of a foot. (These lines are 0.01 foot wide.) There is a target on the front of the rod which can be moved up and down. By means of the vernier on this target, readings can be made to thousandths of a foot. When a reading over 6½ or 7 feet is taken, the target is placed at 6½ or 7 feet, and the two parts of the rod slipped one on the other until the desired elevation is reached, when the two pieces of the rods are fastened; then, by means of a vernier on the back of the rod, the elevation can be read to the thousandth of a foot. This type of rod is used more than any other.

56. Architect's Rod.—The architect's rod (Fig. 32) is a much lighter rod and usually comes in shorter lengths (not over 5½ to 6 feet long) than the Philadelphia rod. It is, however, made in two pieces and slides one on the other similar to the Philadelphia. Its surfaces are varnished, and the graduations are made with narrow black lines. The front piece is graduated in the front, while the back piece is graduated on the side where the vernier for *high* rod is placed. A target moves up and down the front of the rod on which the target readings are made to the thousandth of a foot.

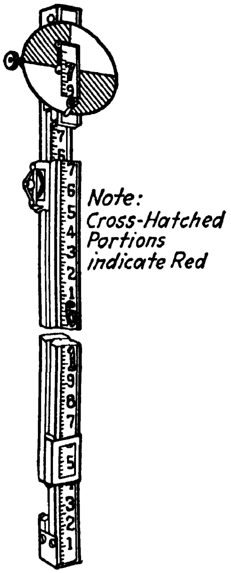


FIG. 31.—Philadelphia rod.

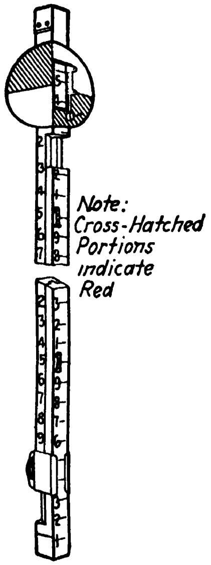


FIG. 32.—Architect's rod.

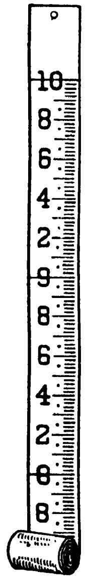


FIG. 33.—Ribbon rod.

The objection to this rod is that it cannot be used with any degree of satisfaction without the target, while the Philadelphia rod can, because its graduations are seen more easily. The architect's rod, however, is less expensive.

57. Ribbon Rod.—The ribbon rod (Fig. 33) is a flexible ribbon, usually of canvas, coated with waterproof paint, and graduated the same as the Philadelphia rod. It can be rolled up and placed in a small space when not in use. When being used, it is tacked on to a 1 by 3- or 4-inch board. No target is used with it. It is cheap, easy to transport from place to place, and well adapted to rough work.

58. How to Read a Rod.—In discussing how to read a rod, only the Philadelphia rod will be considered, as it is the one most generally used.

In learning to read a rod, there are several things to keep in mind—that most level rods (with the exception of those coming with the farm level outfits) are graduated in feet, tenths, and hundredths of a foot; that the width of the black lines on the rod as well as the white spaces between them are 0.01 *foot;* that the rod reading is the distance from the bottom of the rod to the intersection of the level line of sight; that the full foot marks are shown in large red figures with the point of the black line opposite, indicating whether the foot ends on the bottom or top of this line; that the smaller black numbers are tenths of a foot and that the point of the black line opposite them is the place which they represent on the rod; that halfway between the tenth marks will be found one black line which is pointed: this point represents the halfway point between the tenth or, in other words, five hundredths.

On the target will be found a vernier which will read to thousandths of a foot. This reading can be made by determining the line on the vernier which coincides with the top or bottom of a black line. The number on this line on the vernier will be the thousandths of a foot.

In reading a rod, read in the following order: feet, tenths, hundredths, thousandths. Always write the numbers down in decimal form.

When *high rod* is used, the target should be clamped in place as high as it will go on the rod (exactly at 6½ or 7 feet), then the clamp at the top and on one side of the rod loosened, after which the rod is lengthened to the desired point and clamped. Read the same as before, only use the vernier on the back of the rod and read down instead of up.

When high rod is needed and no target is being used, push the back side of the rod up as far as it will go and the levelman can read direct from the instrument.

References

Davis, R. E., F. S. Foote, and W. H. Rayner: "Surveying: Theory and Practice," McGraw-Hill Book Company, Inc., New York.

Davis, R. E.: "Elementary Plane Surveying," McGraw-Hill Book Company, Inc., New York.

CHAPTER V

LEVELING

59. Datum.—The datum or datum plane is the plane to which all the heights or elevations in survey work are referred. It is a plane having an elevation of zero. Usually, mean sea level is taken as the datum in very extensive surveys, but for the average farm survey an arbitrary datum is assumed by establishing a bench mark and assuming that the datum or reference plane is exactly, say, 100 feet below the bench mark.

The elevation of a point is the number of feet it is higher or lower than the datum. Negative elevations are, however, to be avoided by assuming a datum plane lower than the lowest point in the survey.

60. Bench-mark Elevation.—A bench mark is a permanently established mark, the relative height of which above the datum plane is accurately known. A bench mark may be established by selecting some permanent object on the farm, such as a large boulder or section of a concrete curb, and marking on the object a definite and permanent point or spot upon which the rod may always be placed when doing survey work. A 4-foot length of iron pipe driven in the ground to within ½ inch of the surface at a spot where it cannot be disturbed makes an excellent bench mark. The object of the bench mark is to have some point, the elevation of which above the datum is known, to use as a reference point in obtaining the comparative heights of points the elevations of which are unknown. The bench mark is usually designated by the letters "B.M."

61. Differential Leveling.—Differential leveling is a method of leveling used to determine the difference in elevation between two points. In running a line of differential levels, a B.M. is usually the starting point. The level rod is held on the B.M. by the rodman. The levelman sets the level up at some point not too far from the B.M., where the rod can be seen.

The distance that the level should be from the rod is of some importance. If the level is too near, within a foot of the rod, the rod cannot be read. On the other hand, if the level is greater than 200 to 300 feet from the rod, accurate work cannot be done.

A mistake often made by beginners is in assuming that the level must always be set on a straight line running between the two points whose elevations are to be compared. This is not necessary, because distances are not being measured but elevations; hence, it is only a waste of time to try to get the level on line. The level should be set up at the most convenient point to enable the rod to be read.

After the level is set up, the telescope is focused on the rod, and the rodman sets the target at a point indicated by the levelman, which will be where the line of sight through the horizontal cross hair in the instrument and the horizontal division between the red and white target coincide.

Caution: Be sure the level bubble is in the center of its tube at the instant of reading the rod at any point. If necessary, turn the leveling screws slightly in order to accomplish this.

The levelman will need to communicate with the rodman in order to tell him when he has the target at the proper place. This is done to better advantage by signs made with the hands rather than by the use of the voice. Waving the hand up above the head means to raise the target, waving the hands down to the knees, means lower the target. The force with which the hand is waved can be used to indicate the degree to which the target is to be moved. Waving the hand to the right or left over the head means that the rod is out of vertical or plumb and the top should be moved in the direction in which the hand is moved. One hand extended above the head means high rod is wanted. Both hands raised above the head and then dropped to the sides mean that the target is at the right point or, where the target is not used, that the reading has been made. These signs should be learned and used, as they will greatly expedite the work.

When the reading on the B.M. is made and recorded, then the rodman moves to another point on the way toward the point the elevation of which is sought. For a place on which to hold the rod, pick out some surface which is solid and hard, such as a stone, log, sidewalk, railroad, rail, etc. (in using any of these things on which to hold the rod, be careful to mark the point on which the rod is held). If nothing is at hand, a stake should be driven into the ground. This point is called a *turning point* and is usually noted "T.P." The levelman turns the telescope and sights on the rod at this place, and the reading is made as before. When the reading has been made, the levelman moves the level forward and places it in a position ahead of the rod. The instrument is set up, and a reading is made on the rod, which has remained where it was when the last reading was made. The rod is now carried forward to a new T.P., where a reading is made, and then the level is moved, etc., until the final point, the elevation of which is sought, has been reached.

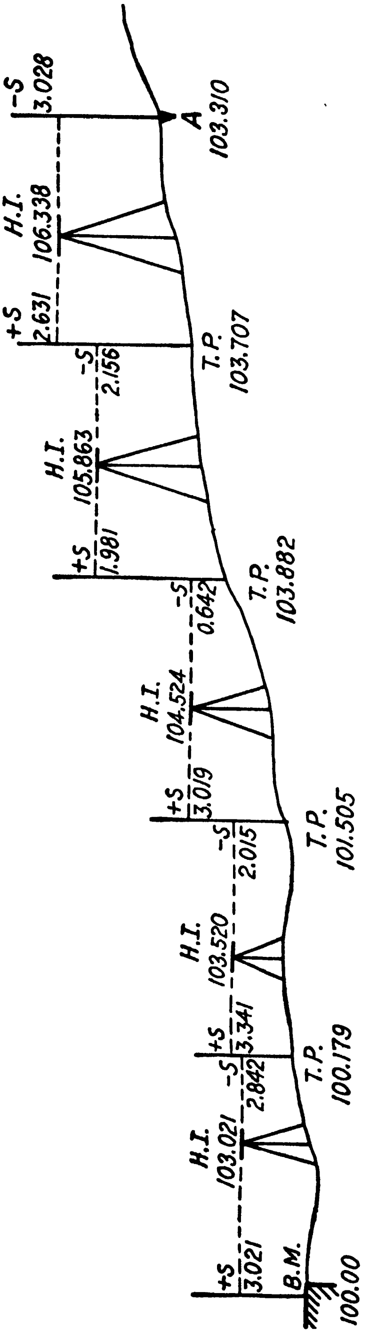


Fig. 34.—Differential leveling.

It is well to keep in mind just what is accomplished by running any kind of levels. This might be stated as follows: The start is made with a place the elevation of which is known and is to be carried from that point with the instrument over to some other point where a comparison of elevations is wanted. *The elevation of some definite point either of a T.P. station or line of sight must be on hand at all times during the operation.*

The computation of the elevation of the rod reading is done as follows: The start was made at the B.M. the elevation of which was known.

This first reading is called a *plus sight,* as it is always added. It is added to the elevation of the B.M. The elevation obtained by this addition is the elevation of the line of sight in the instrument and is called the *height of instrument,* which is designated as "H.I." The second rod reading is a *minus sight,* as it is always subtracted. The minus sight is subtracted from the H.I., which gives the elevation of the T.P. The next sight is a plus sight, which is added to the elevation of the T.P., which gives another H.I., etc. A sample line of levels is shown in Fig. 37. The first rod reading is a plus sight at 3.021 which, added to the elevation of the B.M. (100.00), gives 103.021, the H.I. The next reading was a minus sight 2.842; this subtracted from the H.I. gives the elevation of the T.P., 100.179. The rest are figured in the same way until station *A* is reached.

62. Differential-leveling Notes.—A systematic way of keeping level notes is needed in order to expedite matters. Such a set of notes is given below, and the values found in Fig. 34 are used. It will be seen that there are five columns, each headed differently. The elevation of the B.M. is placed in the first line under the heading "Elevation," while the letters "B.M." go on the same line in the column marked "Station." The first plus sight is placed on the next line in the +S. column. The plus sight added to the elevation of the B.M. gives the H.I., which appears

DIFFERENTIAL LEVELING NOTES FOR FIG. 34

Station	+S.	H.I.	−S.	Elevation
B.M	......	....	......	100.00
	3.021			
T.P	......	103.021	2.842	100.179
	3.341			
T.P	......	103.520	2.015	101.505
	3.019			
T.P	......	104.524	0.642	103.882
	1.981			
T.P	......	105.863	2.156	103.707
	2.631			
A	......	106.338	3.028	103.310
Total	13.993	....	10.683	103.310
	10.683	....	......	100.000
	3.310	....	......	3.310

in the next line, in the H.I. column. Then, the first minus sight is placed alongside of it in the −S. column, and when it is subtracted from the H.I., the elevation of the first T.P. is obtained and is placed alongside in the last column. This same operation is repeated until station *A* is reached.

63. Checking Levels.—A line of levels should always be checked; this is done by running a line back to the B.M., after determining the elevation of the point desired. Upon reaching station *A*, in Fig. 37, a line should be run from station *A* to the B.M., using the elevation of station *A* that was obtained in the line from the B.M. to station *A*. When the B.M. is reached, one should have very nearly the same elevation that was started with, or, in this case, 100.00.

64. Allowable Error of Closure.—The allowable error for differential levels, of course, varies with the object of the levels; sometimes a very small error is allowed, while, in the other cases, where only an approximate elevation is desired, a large error is permissible. *The usual error allowable for ordinary work is* 0.007 *times the square root of the number of hundred feet the circuit includes.*

65. Checking Leveling Notes.—Besides checking the line of levels, the notes should be checked. This is done by getting the difference between the sum of the plus sights and the sum of the minus sights. This difference should be equal to the final difference in elevations. If the differences are not equal, there is a mistake in the additions and subtractions made. For example, in the notes just given, it will be seen that the difference of the two sums mentioned is equal to the difference in elevation between the B.M. and station *A*; hence, the additions and subtractions in this set of notes are correct.

66. Profile Leveling.—The object of profile leveling is to get the elevation of a series of points located in a line at some definite distance apart. The need of such a line of levels would be in laying out roads, ditches, and tile drains.

The first thing to do in preparation for a line of profile levels is to set stakes at the points of the elevations which are to be determined.

Then the level is set up, if possible, where more than one of the points, the elevation of which is to be taken, can be seen. The first reading should be made on the B.M. Should the B.M. be so far away that it cannot be seen from any point near the line of profile levels, then a line of differential levels should be run from the B.M. to one of the stations of the line of profile levels.

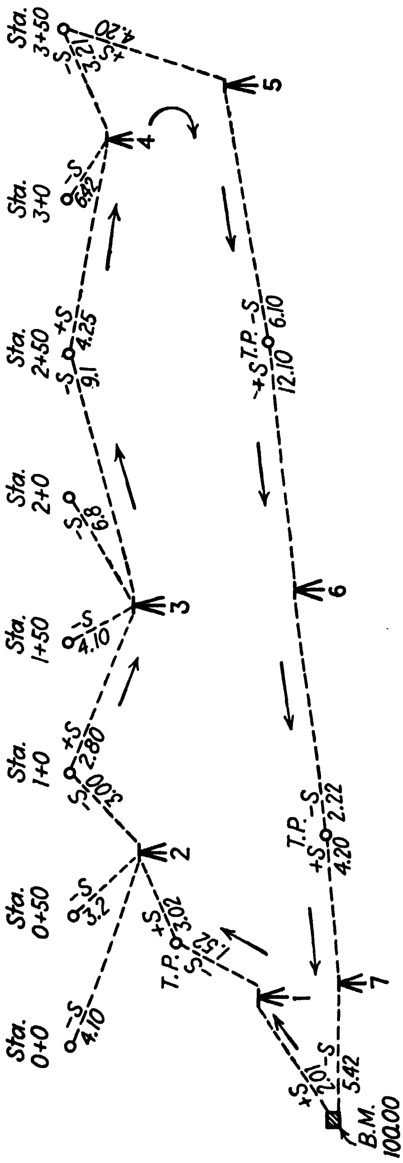


FIG. 35.—Profile leveling.

The first reading on the station, the elevation of which has been determined, will be a plus sight, and it added to the elevation of that station will give the H.I.; next, read on one of the other profile stations, this is, a minus sight; continue to read on as many different profile stations as can be seen. All these readings will be minus sights, as the instrument has not been moved. Each one subtracted from the H.I. will give the elevation of the point on which the rod was held. Now, move the instrument to some point where one of the stations already read on and several of the ones not read on can be seen. Take the first rod reading on the station on which the rod was held at the last set-up; this reading will be a plus sight and, when added to the elevation of the station on which the rod was held, will give the new H.I. Next, read on as many of the forward stations as possible. These readings will be minus sights and, when subtracted from the new H.I., will give the elevation of the stations. Repeat this process as many times as it is necessary to get over the entire line of profile stations. When the last station has been read, run a line of differential levels from that station to the B.M., in order to check.

A specimen line of profile levels is shown in Fig. 35. The sketch is a bird's-eye view of the entire field of operations. There is one T.P. between the B.M. and the first station (0 + 00). Three stations 0 + 00, 0 + 50, and 1 + 00 can be seen from the second set-up. The rest of it can be easily traced out, and, if studied, little trouble should be encountered in learning where to set the level, which reading to make first, and whether the reading is a minus or a plus sight.

67. Numbering Profile Stations.—The numbers given to profile stations are according to their distance from one end of the profile. The end from which the start is made is called the 0 + 00 station. If the next station is 50 feet away, it is called 0 + 50. If it is only 25 feet away, it is called 0 + 25, or, if it is 75 feet away, it is called 0 + 75. When a station is made 100 feet from the start, it is 1 + 00; if 150 feet, it is 1 + 50; if 275, it is 2 + 75; etc.

The reason for numbering the stations thus is to keep track of distances in order to figure grades and to assist in plotting the profile.

68. Profile-leveling Notes.—Below is given a set of notes made up from the profile levels in Fig. 35. By referring to this figure and comparing with these notes, no trouble should be encountered in working them out.

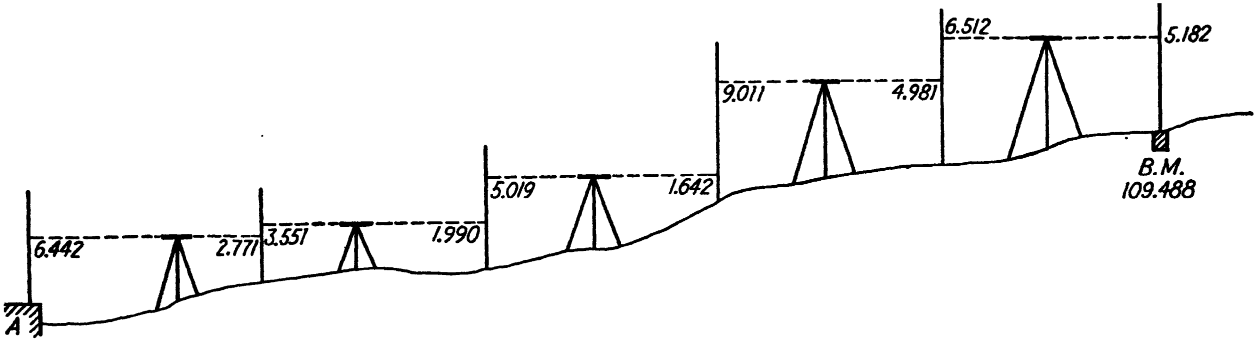


FIG. 36.—Differential leveling for problem 20.

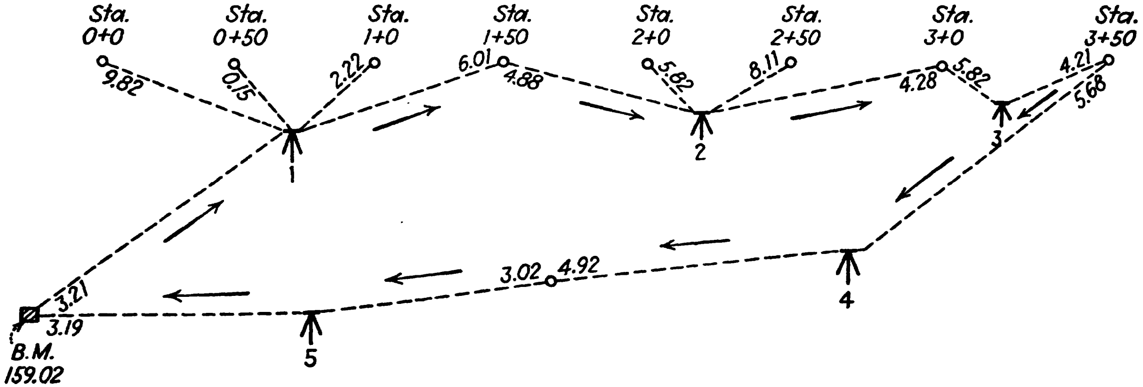


FIG. 37.—Profile leveling for problem 21.

The best way to verify the accuracy of the additions and subtractions in this kind of level notes is to have some other person check them.

Also it is helpful to add all the plus sights and all the minus sights and compare the difference in totals with the difference in elevation of the terminal points. If no error has been made in adding or subtracting the field notes, these differences will be the same.

PROFILE-LEVELING NOTES FOR FIG. 35

Station	+S.	H.I.	−S.	Elevation
B.M.	.....	......	....	100.00
	2.01			
T.P.	.....	102.01	1.52	100.49
	3.02			
0 + 00	.....	103.51	4.10	99.41
0 + 50	.....	......	3.20	100.31
1 + 00	.....	......	3.00	100.51
	2.80	103.31		
1 + 50	.....	......	4.10	99.21
2 + 00	.....	......	6.80	96.51
2 + 50	.....	......	9.10	94.21
	4.25	98.46		
3 + 00	.....	......	6.42	92.04
3 + 50	.....	......	5.21	93.25
	4.20			
T.P.	.....	97.45	6.10	91.35
	12.10			
T.P.	.....	103.45	2.22	101.23
	4.20			
B.M.	.....	105.43	5.42	100.01

Problems

20. Refer to Fig. 36. Make up a complete set of level notes for this sketch and check same.

21. Refer to Fig. 37. Make up a complete set of level notes for same.

CHAPTER VI

ADJUSTING LEVELS

Every well-equipped farm should have some kind of a level. As these instruments are liable to accidents and from long usage are likely to be thrown out of adjustment, it is necessary that methods of adjusting them should be understood. Instructions for adjusting the wye, dumpy, and farm levels are, therefore, given.

In making adjustments on any of the surveying instruments, first determine if it needs adjustment. If it does not, do not tamper with it just for the sake of seeing how it is made. Many a good instrument or machine is spoiled or thrown out of repair because its owner or user is not willing to leave well enough alone. When an instrument needs adjustment, go about making it with extreme care and caution. Surveying instruments are necessarily very delicate and should be delicately treated. Inside the wooden case in which the instrument is kept will be found the necessary pins, etc., to be used in adjusting the instrument. Use them with care, and do not apply large amounts of force, as all adjusting screws should and will function easily when properly handled.

69. Adjustment of Wye Level.—The adjustment of the wye level consists of four distinct adjustments. These should be taken up in the order in which they are given.

70. Adjustment of Cross Hairs.—This adjustment consists of two parts: first, getting the horizontal cross hairs truly horizontal; and, second, getting the line of sight to coincide with the centers of the pivot rings.

To get the horizontal cross hair in a true horizontal position, first level up the instrument and sight on some distant point. This point should rest on the horizontal cross hair. Next, move the telescope about its vertical axis; the point should appear to move along the horizontal cross hair and traverse its entire length. If it does, the cross hair is truly horizontal; if it does not, the four small capstan screws which hold the cross hairs should be loosened, and the cross hairs revolved until the above condition is satisfied, then tighten the screws. If there is more than one horizontal cross hair in the instrument, work with the middle one.

To get the line of sight to coincide with the centers of the pivot rings, have the instrument level as before and sight on some distant point which comes on the intersection of the two cross hairs. Then unclamp the telescope in the wyes and revolve the telescope 180° so that the bubble tube is above the telescope; if the intersection of the cross hairs remains on the point during this operation, the line of sight coincides with the center of the pivot rings. If it does not, then adjust the cross hairs by means of the capstan screws *half the apparent error.* Repeat until correct. The horizontal cross hair can be moved up by loosening the lower capstan screw and tightening on the upper; it can be moved down by reversing the operation. The vertical cross hairs can be moved to the right or left by loosening the screw on the opposite side toward which it is to be moved, tightening on the other side.

71. To Adjust the Line of Sight Parallel to the Axis of the Bubble Tube.—There are two methods of doing this—the indirect and the direct. While the indirect is quicker, it is not so accurate; hence, the direct or peg method will be given here. Two different ways of executing the peg method are given—both satisfactory.

First Method.—The peg adjustment is made by driving two stakes A and B in the ground about 150 feet apart. Set the instrument up in front of A so that when it is leveled up and a rod held on the stake, it will come within ½ or ¼ inch of the end of the telescope. Make a reading on the rod at this point by turning the eye end of the telescope toward the rod and looking in the wrong end of the telescope. Place the point of a pencil on the rod to help in reading it. The center of the field of view is the place to put the point of the pencil, and the rod should be read at this point (Fig. 38). Let this first rod reading be a. Then sight on the rod held on B, this rod reading being b. Next move the instrument to the station B and looking through the wrong end of the telescope, as before, make a reading on B, which is called b'. Likewise, a reading is made on A and is called a'. Now, if the instrument is in adjustment, the difference between a and b will equal the difference between a' and b', because these differences represent the difference in elevation between the two stakes *A* and *B*. If, however, the differences are not equal, then the true difference in elevation will be equal to the mean of the two differences. This can be obtained by adding the two differences together and dividing by two. Then determine, by use of this true difference, what the rod reading should be on *A* (the instrument still being at *B*). This can be done by determining the difference between the *a′* and *b′* difference and the true difference and adding it to or subtracting it from the rod reading *a′*, in order to make the rod read such an amount as to make the difference between it and *b′* equal to the true difference. Set the target on the rod to read this amount, and bring the horizontal cross hair to read on the target, by means of the leveling screws. Then bring the bubble to the center of the tube by means of the bubble adjustment screws at the end of the bubble.

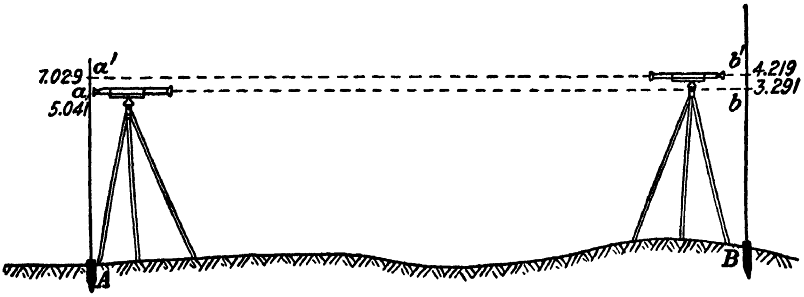


FIG. 38.—Peg method of adjusting levels.

Repeat the entire operation until the level shows that it is in perfect adjustment.

As an example of how the computations are made, the following is given (values are taken from Fig. 41):

Instrument at *A*		Instrument at *B*	
Rod reading on *A* (*a*)	5.041	Reading on *B* (*b′*)	4.219
Reading on *B* (*b*)	3.291	Reading on *A* (*a′*)	7.029
Difference	1.750	Difference	2.810

Mean difference equals 1.750 plus 2.810 divided by 2, equals 2.280. The difference between 2.810 and 2.280 is 0.530. The rod when held on *A* (the instrument still at *B*) would need to read 7.029 minus 0.530, in order to have the correct differences, because the difference between *b′* and *a′* is greater than the true difference.

Second Method.—This method of making the peg adjustment is liked by some because it is thought to be simpler to understand, although it takes a little more care in locating and setting up the instrument.

Put down two stakes from 200 to 400 feet apart. Set up the level exactly halfway between these stakes. If the stakes are 300 feet apart as in Fig. 39, the instrument is set up 150 feet from each stake—on the line between the stakes.

Next, level the instrument up and get the bubble in the center of the tube. Make a rod reading on each stake. If the rod reading at A is called a and the rod reading at B is called b, then $a - b$ = true difference in elevation, because the error in the instrument, if any, compensates, owing to the readings being equidistant from the instrument.

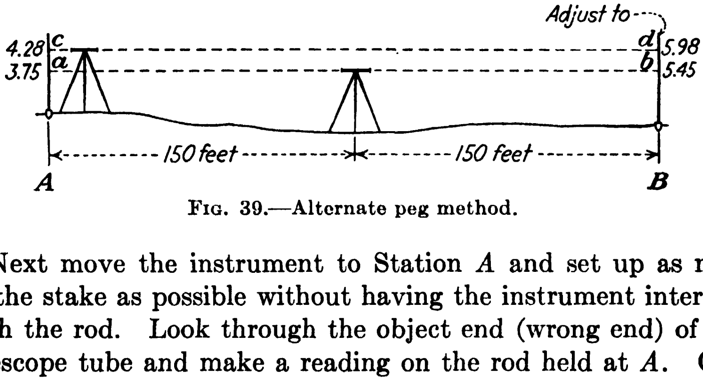


Fig. 39.—Alternate peg method.

Next move the instrument to Station A and set up as near to the stake as possible without having the instrument interfere with the rod. Look through the object end (wrong end) of the telescope tube and make a reading on the rod held at A. Call this reading c. Then make a rod reading on B and call it d.

If the level is in adjustment $a - b = c - d$.

Example.—Use readings given in Fig. 39.

Instrument Halfway between Stakes A and B		Instrument at A	
Rod reading on A (a)	3.75	Reading at A (c)	4.28
Reading on B (b)	5.45	Reading on B is lower, hence add true difference	1.70
True difference in elevation with point B lower than A	1.70	Reading instrument should have, when sighted on B, if in adjustment	5.98

72. To Adjust the Axis of the Bubble Tube in the Same Plane with the Line of Sight.—Level the instrument, then unclamp and rotate it in the wyes a very little; if the bubble remains in the center of the tube, it is in adjustment. If it moves toward one end, then adjust by means of the azimuth screws (the ones that control the lateral movements of the bubble tube). Repeat until correct.

73. To Adjust the Axis of the Bubble Tube Perpendicular to the Vertical Axis of the Instrument.—This adjustment is not absolutely necessary in order to get correct readings but is made as a matter of convenience, as it insures that the instrument, when leveled, can be turned in any direction and will remain level.

To determine whether the level needs this adjustment, first level it up over two screws and then over the other two; repeat two or three times. Then turn the telescope through 180°; if it remains level, it is in adjustment. If, however, when turned, the bubble moves toward one end or the other, it is out of adjustment. Proceed to correct half the distance the bubble is out by means of the leveling screws and the other half by adjusting screws on the bottom of the wye. Repeat until in adjustment.

74. Adjustment of Dumpy Level.—The methods used in adjusting a dumpy level are somewhat similar to those used for the wye level, but the adjustments are taken up differently and made at different points. Care should be taken to make them in the order given. There are three to be made.

75. Adjustments of Cross Hairs.—The horizontal cross hair should be horizontal, and the method used in determining its adjustments and making same is similar to that used for the wye level and given in the first part of Art 70.

76. To Adjust the Axis of the Bubble Tube Perpendicular to the Vertical Axis of the Instrument.—The testing of the instrument to determine its condition of adjustment is the same as given for the wye level in Art. 73. To make the adjustment, half the correction is made with the leveling screws the same as for the wye level, but the other half is made by raising or lowering one end of the bubble tube instead of the wye on the wye level.

77. To Adjust the Line of Sight Parallel to the Axis of the Bubble Tube.—The determining of the condition of the level is the same as given in Art. 71. If out of adjustment, the proper reading is determined as before, but instead of bringing the instrument to this reading by means of the leveling screws, the cross hairs are moved up or down until they read correctly, and the leveling screws are not touched.

78. Adjustment of Farm Level.—The Bostrom & Brady farm level is adjusted a little differently than either the wye or the dumpy level. Below are given the manufacturer's directions for adjustments. The usual practice followed by most users is to make the level-tube adjustment first.

Level-tube Adjustment.—The level tube, as shown in Fig. 40, is held in position by screws *BB′* and *CC′*, as shown. To find out if the bubble is right, turn the level so that the level tube is over the leveling screws 1 and 2, as shown in Fig. 41.

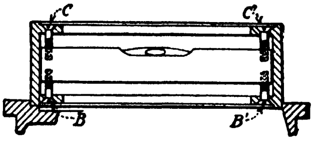


Fig. 40.—Adjusting bubble tube of B. & B. farm level.

Bring the bubble exactly between the lines by the screws 1 and 2. Then swing the turret around to the position shown in Fig. 42, which is end for end to the first position. If the bubble does not come exactly to the center between the lines, as at first, correct half the amount it is out by the screws *BC* or *B′C′*, shown in Fig. 40, by loosening screw *B* on the low end of the tube and tightening on the screw *C*, always being careful not to tighten the screws too hard, but just firm enough to hold the tube where it should be. Repeat this test and the adjustment until the level bubble stands between the lines in any position of the turret. After bringing the bubble to the center over the screws 1 and 2 (Fig. 41), turn the turret so the telescope is over the screw 3, as in Fig. 43. Then work the screw 3 up or down until the bubble comes between the lines. Repeat this operation every time the level tube is adjusted so as to keep the plate on a level as nearly as possible, until the level tube is in perfect adjustment.

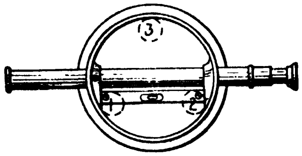


Fig. 41.—First position of telescope.

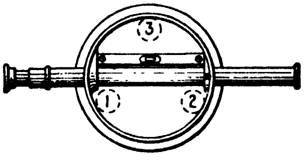


Fig. 42.—Position of telescope when reversed.

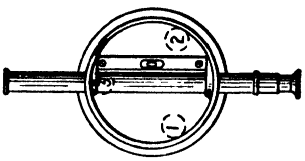


Fig. 43.—Final position of telescope.

Line-of-sight Adjustment.—By referring to Fig. 44 it will be seen that the center line of the telescope must be parallel to the edge of the turret. To accomplish this, sight through the telescope at the target or at a (nearly horizontal) line on some other object at least 150 feet distant. Make the horizontal cross hair in the telescope coincide with the target or line by manipulating the leveling foot screws 1, 2, and 3 (Figs. 41–43). Now lift the turret out and replace it in an inverted position, so that the edge that rested on the plate is up and the other edge down, and sight again at the target or line. If the horizontal cross hair coincides with the target or line just as it did in the first position, the adjustment is all right. However, if it shows above or below the line, then correct half the difference by the screws *A* and *B* (Fig. 44) by loosening one and tightening the other so as to raise or lower the telescope tube in the turret; the other half of the difference should be adjusted by the screws under the plate. Then repeat the operation and see if the cross hair in the telescope and cross on target come together either way the turret is turned, up or down; if not right, carefully repeat the adjustment until it is right, being careful not to put too much pressure on the screws and to correct only half the amount that is out, for if all the difference is corrected when the turret is turned over, it will be found that it is just as much out as it was in the first place. This adjustment should be looked after at frequent intervals, as screws are liable to get loose and change the original adjustment. It should be understood, of course, that, while making this adjustment, the turret must be released from the plate so it can be lifted out and reversed.

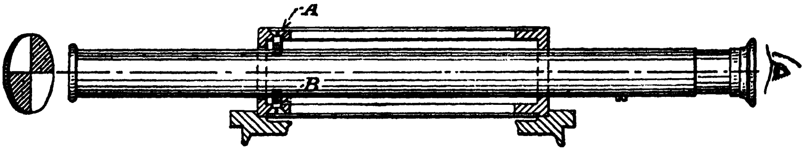


Fig. 44.—Telescope and turret of B. & B. farm level.

References

Davis, R. E., F. S. Foote, and W. H. Rayner: "Surveying: Theory and Practice," McGraw-Hill Book Company, Inc., New York.

Davis, R. E.: "Elementary Plane Surveying," McGraw-Hill Book Company, Inc., New York.

CHAPTER VII

LINES AND ANGLES

79. Transit.—The transit is an instrument whose telescope can be revolved on a horizontal and vertical axis (Fig. 45). Graduated circles are attached, by means of which the size of the angles in both the horizontal and the vertical planes is obtained. Besides these, it is provided with a magnetic needle which allows the bearing of lines to be determined. The transit is not of enough use to the average farmer to warrant purchasing one, as it is very costly. The addition of the horizontal graduated circle to the level, making what is known as an *architect's level,* is all that the average farmer needs.

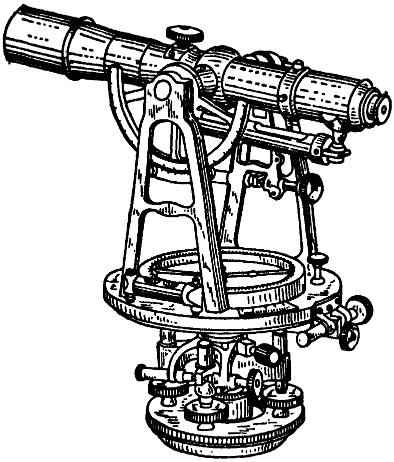


FIG. 45.—Transit.

80. Reading Angles.—The reading of horizontal angles with a transit or architect's level is a very simple process and, as a rule, is more accurate than the steel-tape determinations. The instrument, either a level or a transit, is centered over the point which forms the vertex of the angle. This is accomplished by means of a plumb bob which is attached to the instrument. When the instrument is centered, it should be leveled, and then the telescope turned toward the flag or range pole which is held on the line that bounds one side of the angle. The telescope is clamped in this position, and the circle set to read zero; then the telescope is unclamped and turned until it sights the flag pole on the other boundary of the angle. The angle is now read on the graduated circle.

In reading the angle on the graduated circle, a small vernier will be found attached to the spindle of the instrument which revolves with the telescope. The graduated circle is independent of this vernier but adjacent to it. The circle can, as a rule, be moved and set so it will have its zero on the zero of the vernier when an angle is to be read. On transits, the circle is usually graduated into half-degrees, while on architect's levels and kindred instruments, the graduations are usually only to degrees. As the latter type of levels is used by agricultural students, the method of reading angles with it will be explained. The circle degrees are numbered every 5 or 10° and run up to 90 or 180°, where they start again at 0 and repeat until the full 360° of the circle is covered. When an angle greater than 90 or 180° is to be read, care must be taken to make the proper addition. The vernier is usually graduated to read to 5′ sometimes to 10 or 15′. The division on the graduated scale directly opposite or the one just past the zero of the vernier gives the degree reading. Be careful to read the angle on the circle in the same direction in which the telescope is moved. For the rest of the reading, find the line on the vernier which coincides with a line on the graduated circle. The number of minutes that this line on the vernier represents is the number of minutes to be added to the degrees obtained by the reading at the zero of the vernier.

81. Bearing of a Line.—In surveying land, it is not only necessary to be able to read the angle which two lines make with each other, but it is also desirable to know what the bearing of a line is, as the ownership of land is continually changing, and the boundaries are located by magnetic bearings. The bearing of a line is obtained by the use of a compass. This compass may be a part of a level, transit or a surveyor's compass. The latter has no telescope.

In using the compass, first set the instrument over some point on the line the bearing of which is to be determined. Level the instrument and lower the magnetic needle of the compass so that it will swing free. Next, sight the telescope, or whatever is used for sighting, along the line the bearing of which is wanted. Then read the bearing on the graduated circle at the point of the needle. This bearing will be less than 90° and either east or west of north or south. For example, if the needle stands 45° east of north, then the bearing is N. 45° E. Compasses on surveying instruments are lettered N.W.S.E., in clockwise direction, to assist in making these readings.

In using a magnetic needle to get bearings, all steel and metal should be kept away from it in order to prevent the needle from being attracted out of its true course.

As the magnetic pole is not at the true north pole, a correction must be made in using the compass in order to get true north. The amount that the magnetic needle deviates from the true north pole is known as the *magnetic declination* and it varies in value for different parts of the country. There is also a yearly variation of declination values for any one spot on the earth's surface. This declination may be east or west, according to the place in this country at which the compass is used. By *east* or *west* declination is meant the pointing of the magnetic needle east or west of the true north.

82. Running a Straight Line.—It is often necessary to project a straight line. This is a very simple process with a transit or a level whose telescope will move in a vertical plane, but a common level will project a straight line only if the land is flat. If the land is hilly, it will not work well, because the telescope will not move in a vertical direction.

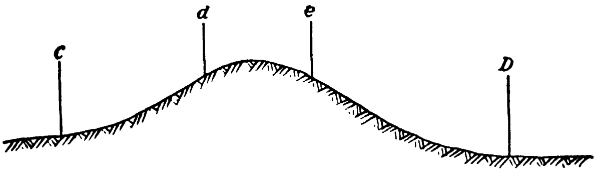


FIG. 46.—Running a straight line over a hill.

To lay out a straight line, set up and level the instrument over the starting point, which is usually one end of the line. Sight on the point which will establish the direction of the line, set the graduated circle to read zero on the vernier, and turn the telescope through 180°. The telescope will be looking along the line desired. Locate a distant point on this line, and then set the instrument up over that point and proceed as before, continuing until the line is run the desired length.

Without the use of an instrument, straight lines can be projected with a certain degree of accuracy by *sighting*. The degree of accuracy is, of course, dependent on the ability of the one doing the sighting to see straight. In projecting a straight line over a hill between two points not visible to each other without the use of an instrument, the following method is useful:

Refer to Fig. 46, let C and D be the two points. Select points d and e on top of the hill so that they are both visible from either C or D. Set the range pole at any approximate location for e and another for d in line with Ce. Sighting, then, from d to D, range e in line. Continue until points C, d, e, and D are in a straight line.

83. Laying Out Building Foundation.—In Art. 37, the method of laying out the foundation of a building with the tape alone was described. It is much more easily done if an architect's level is at hand. Figure 47 shows the completed foundation laid out and ready for the trenches to be dug. The first thing to do is to set the instrument up over one of the corners of the building, say, A, where a stake is set with a nail in the top of it which marks the exact corner. The instrument is sighted along line AD, and D located by means of the tape. The instrument is then turned through 90° and sighted along line AB; B is thus located. Batter boards can be set up at all corners, having them 2 or 3 feet away from the actual corners. The boards should all be level and of the same elevation. This can be done by using the level and having the same rod reading for all of them. Points P, G, H, and L on the batter boards can all be located with the instrument at A. Now, move instrument and set up over B, sight back on A, turn instrument through 90°, and locate C with tape. Locate points N and K. This leaves only points R and M to establish, and they can be located with the eye, a cord, or by setting up the instrument over C.

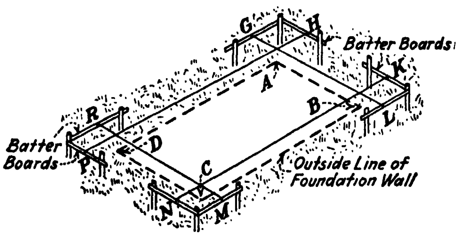
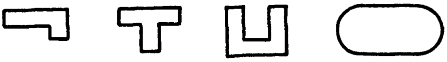


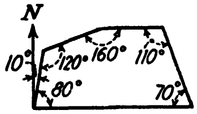
FIG. 47.—Laying out building foundation.

Problems

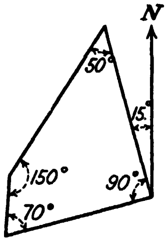
22. How would the following farm buildings be laid out (*a*) with tape alone, (*b*) with tape and architect's level?



23. Compute the bearings of the lines in the following figure.



24. Compute the bearings of the lines in the following figure.



CHAPTER VIII

TOPOGRAPHICAL SURVEYING

84. Topographical Surveying Defined.—The purpose of a topographical survey is to determine the actual size and shape of the field or farm being surveyed, the location of all farm buildings, roads, ditches, streams, and fences. Sufficient elevations should also be taken to show by contours the topography of the land.

85. Methods of Making Surveys.—There are four common methods used in making such surveys—stadia, compass, plane table, and laying out in squares.

86. Stadia Method.—This method uses a transit with stadia wires, which enables the instrument man to read the distance of the rod from the instrument. The different elevations are obtained by reading the vertical angle and computing the difference in elevation. The path of the transit set-ups and the rod readings are kept by means of horizontal-angle readings. This method is used by engineers only on large surveys, as the necessary equipment is expensive.

87. Compass Method.—This method uses a level with stadia wires and a compass. The distance of the rod from the instrument is determined by stadia, and the path which the rod and instrument travel in making the circuit while taking elevations is kept by reading the bearings of the path traversed with the compass. The difference in elevations is obtained by means of the level. This method frequently is used by government engineers in drainage surveys. The equipment is, however, more expensive than the average farmer can well afford.

88. Plane-table Method.—The use of the plane table in this method involves the reading of distances by stadia, elevations by vertical angle, and path of travel by plotting it on the map at the time the readings are made. It, or a modification of it, is used by the government in making the soil surveys of the various counties in the states and by engineers of the army and the U. S. Geological Survey in their topographical work.

89. Laying-out-in-squares Method.—This method is by far the best for the agricultural student to use, as it does not call for expensive equipment and is not very complicated.

It consists in first measuring the boundaries of the field to be surveyed and determining the lengths of all the sides and the angles between the sides.

Next, the field is laid out in 100-foot squares, and a stake set at each corner of these squares. The best way to do this, if the field is not square, is to take one of the long sides which is straight and measure it off in 100-foot lengths. Then project a line perpendicular to this side at each of these 100-foot points and set stakes on these perpendicular lines at each 100-foot mark. Continue until the field is completely divided.

Wherever the lines cross a road, ditch, fence, or building, take a plus distance on this point; that is, note how many feet it is from the nearest 100-foot mark. In this way, these various objects can be located on the map.

After the field is staked out, the next step is to take elevations on the ground at the side of each of the stakes. This is done as it was for profile leveling; *i.e.*, first locate a bench mark, then set the instrument up at some point where a large number of stations can be read from one set-up. Take a plus sight on B.M., and get H.I. (height of instrument). Then take minus sights on as many stations as possible. When all the readings possible have been made, move the instrument, take a plus sight on some station the elevation of which has been found, and then make as many minus readings on stations as possible. Continue this process until all stations have been read, then check on B.M. The notes for the levels will be made the same as for the profile leveling, except that the numbering of the stations is different.

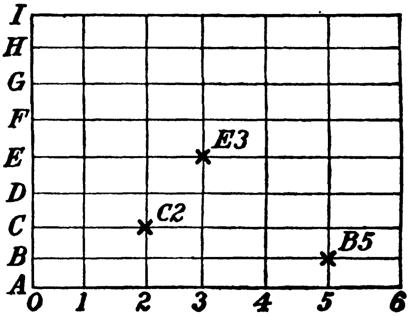


FIG. 48.—Method of numbering stations for topographical surveying.

To number the stations: Letter the 100-foot lines on one side of the field, and number the 100-foot lines which are perpendicular to them. Then each intersection will have for its station mark a letter and a number. As shown in Fig. 48, station *C*2 is on line 2 and line *C*; likewise, station *E*3 is on lines *E* and 3; also, station *B*5 is on lines *B* and 5. By using this system, each station is given a distinctive marking and may be easily located on the map when plotting the survey.

90. Map Defined.—A map is a representation on paper in true proportion of the outline of a given piece of land. Besides the outline, there may be added roads, railroads, fences, streams, buildings and other features.

91. Topographical Map.—A topographical map is a map having, in addition to the above-mentioned representation, the character of the surface of the land shown by contour lines denoting differences in elevation and the condition of the land surface—whether tilled, untilled, swamp, woods, etc.—noted by the standardized symbols.

92. Plotting a Boundary Line.—All maps are drawn on paper to a given scale, in order that they may be in true proportion. By *scale* is meant the arrangement whereby a number of inches, or an inch, or part of an inch will represent on the map, 1 foot, 10 feet, or 100 feet of actual distance. When a part of an inch is used, it is usually a decimal part, such as one tenth, or one twentieth. On the market are to be found certain rules called *scales* which have inches divided in these various ways, to facilitate the laying off of the desired lengths. The most common is a triangular box-wood scale, which has six different divisions represented on it: 1 inch equals 10 feet; 1 inch equals 20 feet; 1 inch equals 30 feet; 1 inch equals 40 feet; 1 inch equals 50 feet; and 1 inch equals 60 feet. Any of these divisions can be multiplied by 10 or 100 and used the same way.

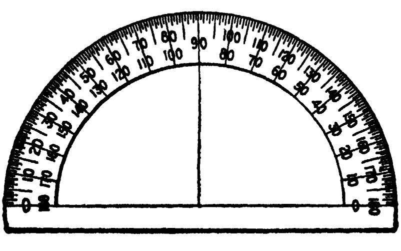
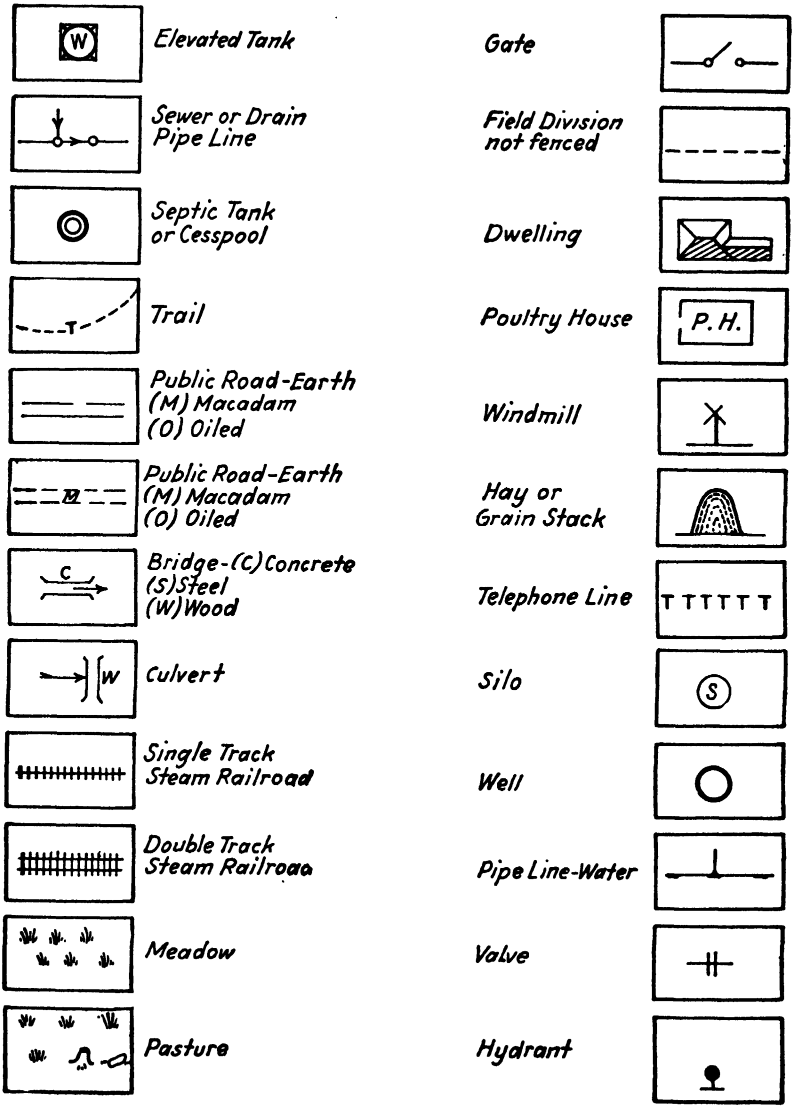


FIG. 49.—Protractor.

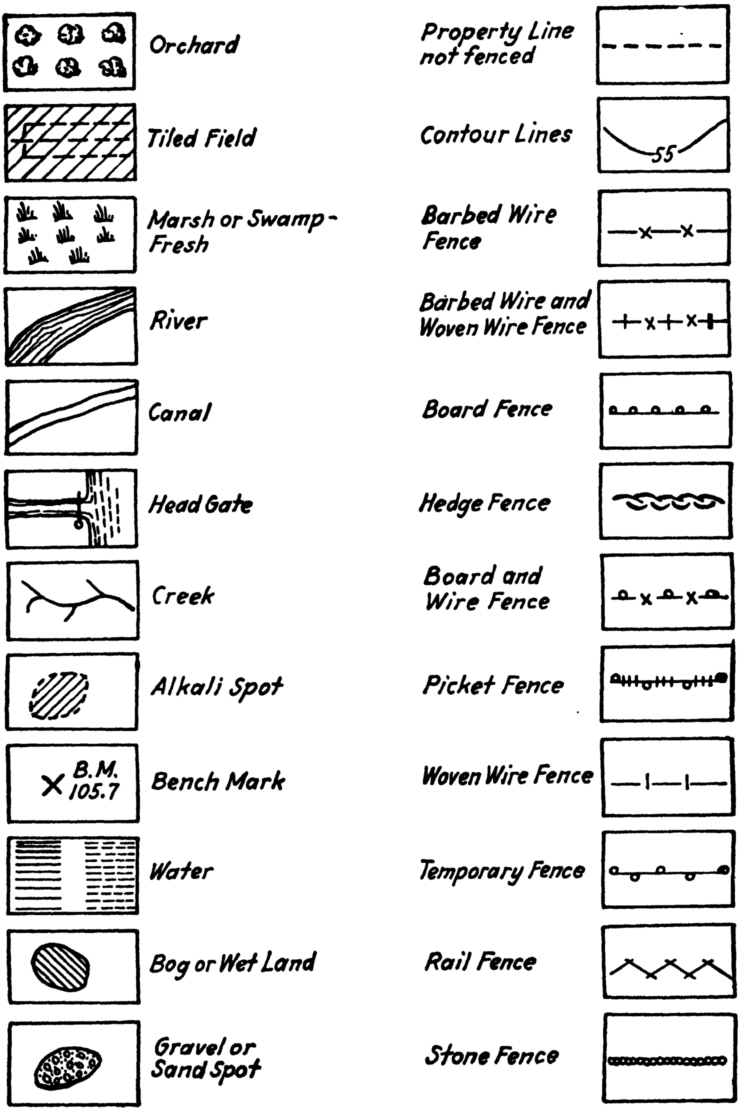
93. Plotting Angles.—In plotting the boundary lines of a given piece of land, the length of the lines can be easily and quickly laid out by means of the scale, but to lay out the angle each side makes with the other necessitates the use of a protractor (Fig. 49). This is a piece of paper, metal, or celluloid, in the shape of a half-circle. The curved side is divided into degrees, while at the center of the straight side is a vertical mark. When an angle is to be laid off, the straight edge is laid along one of the boundary lines, and the vertical mark is placed at the point where the angle is to be made; then the size of the



Symbols for topographical maps.

angle is read in the curved edge, and a pencil mark made at this point. A line through this point and the point on the boundary line at which the angle is to be made will form the required angle.

If a protractor is not at hand, the angles can be laid off by means of the sine or tangent method as explained in Chap. III, using the scale instead of the tape.



Symbols for topographical maps.

94. Map Symbols.—The different things, such as fences, roads, ditches, streams, railroads, conditions of land, etc., are all represented on the maps by certain recognized symbols. There are sometimes many different symbols to represent the same things. The American Society of Agricultural Engineers, has attempted to eliminate the confusion resulting from this fact by establishing a set of symbols which is considered standard practice and which is used by all members of the society. A few of the most important of these are given on the following pages. The entire set can be obtained from the secretary of the society at a nominal cost.

95. Lettering.—Every map should have a neat title. A representative one is shown in Fig. 50. See, also, Fig. 52, which shows where titles should go on the paper and gives an idea about the kind of title to use.

MAP
of
____
AGRICULTURAL ENGINEERING DEPARTMENT
A.& M. College of Texas
Scale: 1"=100'
Samuel Smith Sept.4,1938

FIG. 50.—Map title.

Maps also require the addition of dimensions and notes, all of which should be lettered freehand in a style that is legible, uniform, and capable of rapid execution. Nothing will mar the appearance of a drawing more than poor lettering. Good lettering can be acquired only by long and continued practice, bearing in mind the general form of all the letters.

The fundamental principle of good lettering is good design, and this is secured by:

1. Simplicity of style.
2. Uniformity of effect.

Simplicity of style is secured by keeping the letters as free as possible from needless strokes.

Uniformity of effect is secured by making the letters appear to be of the same general height and the same general width.

The spacing should also appear to be uniform. If all the letters were of the same general form and of the same general size, this uniformity of effect would be very easy to secure, but as they are not, it is necessary to vary the letters in both height and width.

For the purposes of this discussion, the capital letters are assumed to be of the general size 5 units high and 3 units wide, and each of the letters should be made to appear to be of this general size. In order to get this appearance, letters are made to vary in size.

Letters like B, C, and D, which have rounded corners, are made a trifle wider than 3 units; likewise, A is wider at the base than H, to counteract the narrow effect at the top. The exceptions to this rule are L and F, which are a trifle narrower.

Where the letter touches its upper or lower limits only by tangency, it must be made to exceed these limits in order to appear as high as the others. O, C, G are examples. A and V also exceed the limits at the points, unless the points are blunted.

Letters having upper and lower parts, like B, K, E, Z, S, have lower parts slightly wider and larger, so as to produce an effect of stability. The midhorizontal strokes of B, E, F, H, R and the crossing points of X are placed a trifle above center for this same reason. The midhorizontal strokes of A, G, and P, however, are placed a trifle below the center of the letters.

In the lower-case or small letters, the ascending letters are all made 5 units high. The bodies of the letters are made 3 units wide. The descending letters extend 2 units beneath the lower guide line, so that their total height is 5 units. There is a great similarity in form among the small letters. Six of them may be formed by making the letter o and adding single strokes to it; a, b, d, g, p, and q are formed in this way; c is a partially formed o, and e is made the same as c, with a horizontal stroke in addition. h and k are formed from the letter l, with two inclined strokes in addition for the k, and one for the h. t is a letter 4½ or 5 units high, with a horizontal bar crossing it three-quarters of the way up. n, m and r use the letter r as a basis. w is formed by making two v's side by side, and y is a v with a vertical stroke two units long at the lower end.

In order to keep the letters of uniform height, *guide lines* must be drawn, and the lettering done between them. If any difficulty

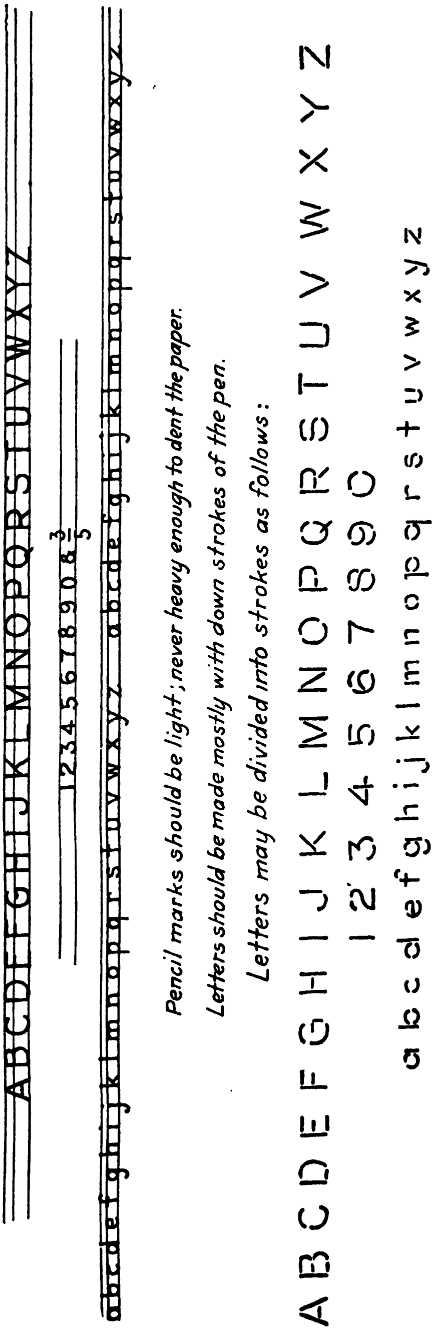

ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890 & 3/5
abcdefghijklmnopqrstuvwxyz abcdefghijklmnopqrstuvwxyz
Pencil marks should be light; never heavy enough to dent the paper.
Letters should be made mostly with down strokes of the pen.
Letters may be divided into strokes as follows:
ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890
abcdefghijklmnopqrstuvwxyz

Fig. 51.—Lettering.

is experienced in keeping the sides of the letters parallel, draw a number of vertical lines at intervals across the guide lines and use these as guides.

Spacing ranks second to form in the importance of its influence on the appearance of the letters. An effect of uniformity should be secured. No definite rules can be given as to how to secure this, as securing it depends, to a great extent, on the artistic perception of the draftsman. Practice and observation, however, will determine the amount of spacing to leave between the individual letters.

The *slope* of the letters may be either vertical or inclined. Here again uniformity is essential. Vertical letters are preferred for captions and important items and inclined letters for details on maps.

As much as possible make the different lines of the letters with *downward strokes* of the pen. Their order and direction are shown in Fig. 51.

96. Contour Lines.—In order to show the topography of the land on a map and thus get a topographical map, contour lines are used. A contour line is a line which passes through points on the surface of the ground which are of equal elevation. That is, a 50-foot contour line will pass through points 50 feet above the datum. To get an idea of just what this means, imagine a small lake with the surface of its water at rest. The edge of that surface, where the water touches the land, will be level, and all points on it will be the same distance above any datum. The edge of this lake surface is a contour line; if it is 50 feet above a certain datum, it would be the 50-foot contour.

In order to get a better idea of just what contours are and to assist in plotting them on maps, the following *contour-line characteristics* are given:

All points on a contour line are the same elevation.

All contour lines close either within the confines of the map or outside; where they close outside the boundaries of the map, they are stopped at the boundaries.

All contours which close within the boundaries of the map show either a depression or a rise.

Contours never cross each other except in case of an overhanging cliff.

Contours equally spaced represent a uniform slope.

Contours in crossing a valley run up the valley at one side, cross the stream, and run back on the other side.

The steepest slope is always at right angles to the contours.

97. Making Topographical Maps.—The first thing to do in drawing a topographical map is to select the scale which is to be used. Then draw the boundary lines, after which the space inside these boundary lines should be ruled off in 100-foot squares, and each intersection numbered in pencil, just as was done in the field. (It is assumed that the method described in Art. 89 was used in the survey.) After this, the elevation of the intersections should be noted on these points. Each building, road, stream, etc., should be located with the proper symbol. Now the contour lines are ready to be put in. Before starting on these, the vertical distance between contours must be decided on. Contour lines may be shown every foot, 2 feet, 5, 10, 25, or 100 feet. In comparatively flat country, 1- or 2-foot contours are used, while, in rough country, the distance between contours must be greater. The reason for this is that the use of 1-foot contours on a very steep slope would bring the contours so close together that it would be impossible to draw them distinctly and to distinguish what they were after they were drawn.

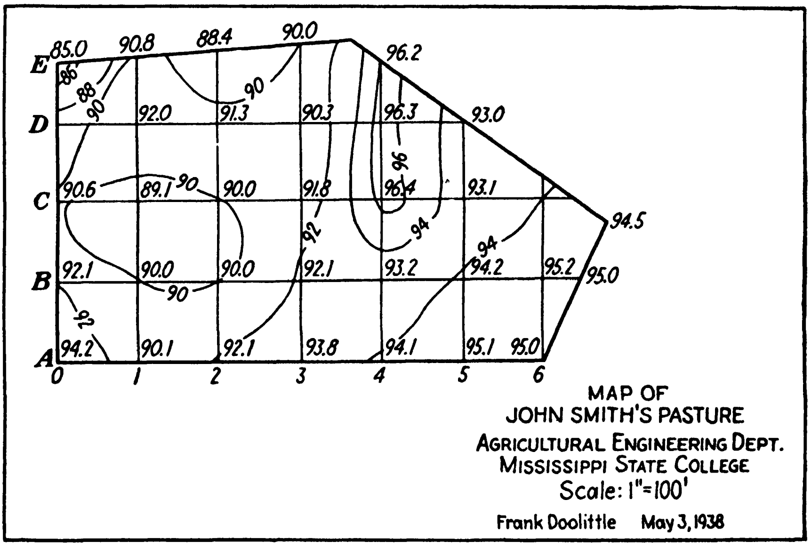


FIG. 52.—Contour map.

When putting the contours in, it is well to start between two stations and draw in as many short lines as there will be contours between these two stations and then take the next two stations and do the same. Join the like contours together. Continue until all the contours are run in. Figure 52 shows a map with contours on it. Two-foot contours are used, although it would have been possible to use one-foot contours. A little study of Fig. 52 should enable the student to have no difficulty in plotting the contours on a map. After the contours are on the map, ink in the boundary lines, contour lines, symbols representing buildings, streams, etc.; but erase all 100-foot subdivision marks.

98. Profile Defined.—A *profile* is a graphical representation of the surface of the earth along some given line.

99. Plotting Profiles.—Profiles are usually plotted on special ruled paper called *profile paper.*

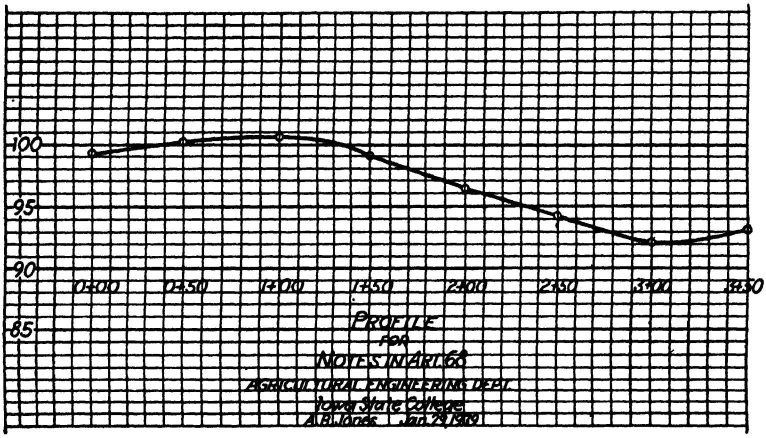


FIG. 53.—Typical profile.

The profiles are, of course, plotted to a certain scale, just as maps are. In the case of map boundaries, only the length and direction is taken into account, and a scale used; while, in the case of the profiles, the length and elevation of the line between two points are taken into consideration. For each direction, the distance is scaled, and usually the scale used is different for both directions. For instance, 1 inch equals 1 foot might be used for vertical direction or the elevation; and 1 inch equals 20 feet, for the horizontal direction or the length of the profile line.

The lower left-hand corner of the profile is usually taken as station 0 + 00 of the profile, and the other stations are laid off to scale and to the right. This same corner is then given an elevation 2 or 3 feet lower than the elevation of station 0 + 00 or of any station of the line which has a lower elevation. The scale of elevations is marked off on this left-hand edge.

To plot the elevations, take station 0 + 00. First locate its elevation on the vertical line running through station 0 + 00 and place a cross at that point, then take the next station, say, station 0 + 50; this would be horizontally 50 feet to the right according to scale from station 0 + 00. When this point is found, go up along the vertical line above this point until the horizontal line is met which comes from the elevation of this station in the scale at the left. Place a small cross at this point. Repeat the operation until all the elevations of the stations are plotted. Then draw a line through the various crosses, and there will be shown a true representation of the surface of the ground.

Figure 53 shows a profile makeup from the notes given in Art. 68.

100. Value of Profiles.—Profiles are used to aid in the installing of tile drains and in building roads, ditches, etc. They are valuable for this use, as they picture the lay of the ground and enable the best grade to be given with the least trouble to the various undertakings mentioned.

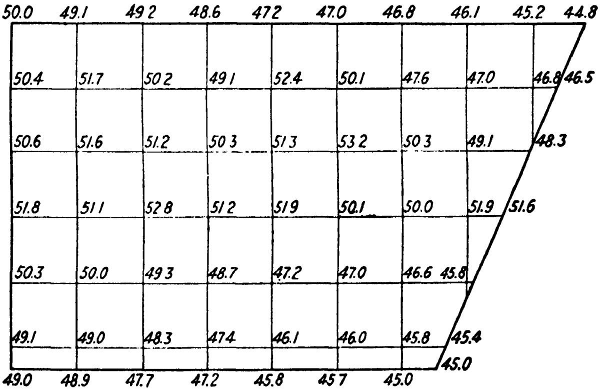


FIG. 54.—Map for problem 26.

Problems

25. Plot on profile paper profiles for Fig. 37.
26. Fill in contours on map shown as Fig. 54.

References

DAVIS, R. E., F. S. FOOTE, and W. H. RAYNER: "Surveying: Theory and Practice," McGraw-Hill Book Company, Inc., New York.

DAVIS, R. E.: "Elementary Plane Surveying," McGraw-Hill Book Company, Inc., New York.

CHAPTER IX

COMPUTING AREAS

101. Computing Areas.—It is often necessary to determine the area of a piece of land for the purpose of purchasing it, selling it, determining crop yields, or making subdivisions.

The usual unit used is the acre, which consists of 43,560 square feet. In determining the number of acres in a given piece, its area is first computed in square feet, then changed to acres.

102. Area of a Square.—The area of a square is the square of one of its sides.

103. Area of a Parallelogram.—A parallelogram is a figure with four straight sides the opposite sides of which are parallel (Fig. 55). The area of this figure is equal to the base times the altitude.

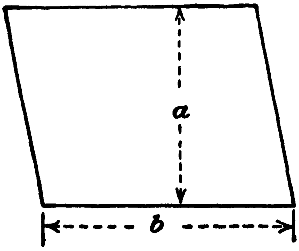


Fig. 55.—Parallelogram.

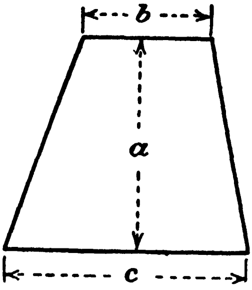


Fig. 56.—Trapezoid.

104. Area of a Trapezoid.—A trapezoid is a figure having four straight sides only two of which are parallel (Fig. 56). The area of this figure is equal to the altitude times the mean length of the parallel sides.

105. Area of a Triangle.—There are three different methods used to get the area of a triangle.

1. *Base and Altitude Given.*—The area of a triangle is equal to one-half the base times the altitude (Fig. 57).

2. *Three Sides Given.*—Let the sum of the sides of a triangle be equal to two times S, then the area of the triangle equals $\sqrt{s(s - a)(s - b)(s - c)}$ (Fig. 58).

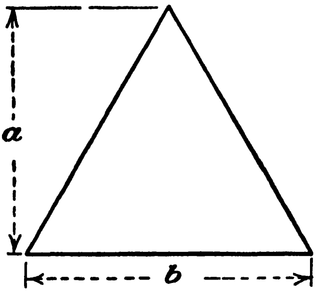


FIG. 57.—Triangle.

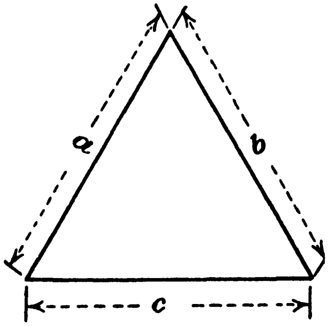


FIG. 58.—Triangle.

3. *Two Sides and the Included Angle Given.*—The area of a triangle is equal to one-half the product of the two sides and the sine of the included angle (Fig. 59).

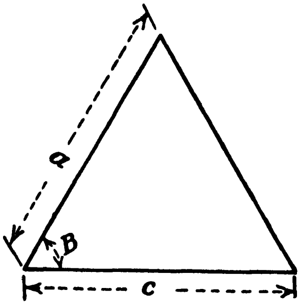


FIG. 59.—Triangle.

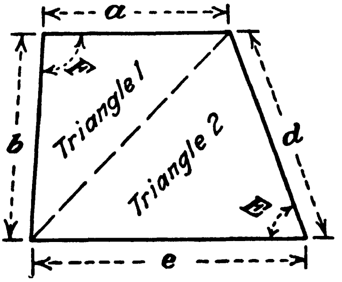


FIG. 60.—Trapezium.

106. Area of a Trapezium.—A trapezium is a figure having four straight lines no two sides of which are parallel. Divide the trapezium into two triangles and determine the area of each triangle, then add the two areas together (Fig. 60).

107. Area of a Many-sided Figure.—In obtaining the area of a many-sided figure, it is best, if possible, to resolve it into a number of triangles and then measure the sides and angles of the triangles.

Figure 61 shows a five-sided figure which has been broken up into three triangles. The areas of triangles 1 and 2 can be obtained as given in Art. 105, third method. To get the area of triangle 3, it will be necessary to have the length of the two sides not given. If it is impossible to measure these two sides, then they can be obtained by solving for the corresponding two sides in triangles 1 and 2.

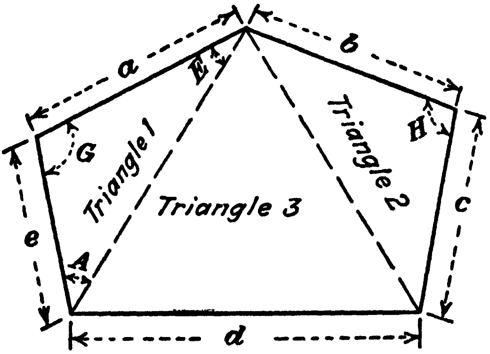


FIG. 61.—Polygon.

108. Area of a Figure with Curved Boundary.—In determining the area of a figure with a curved boundary, two formulæ are available—the trapezoidal rule and Simpson's one-third rule. Whichever rule is applied, the measurements, as shown in Fig. 62, should be made. The distance between ordinates should be equal; that is, the distance between the points where each offset is measured should be the same, for example, 10, 20, or 30 feet. Then the lengths of the offsets are measured, $h_0h_1h_2h_3$, etc.

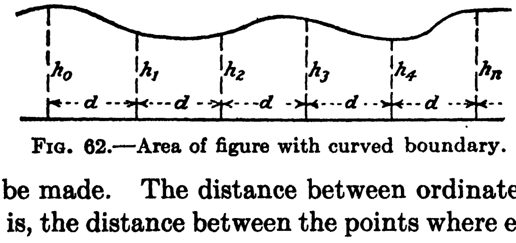


FIG. 62.—Area of figure with curved boundary.

Σh = sum of offsets, except end offsets

h_0 and h_n = end offsets

With this information, the approximate area can be found with either of the two rules mentioned.

Trapezoidal Rule:

$$\text{Area} = d\left(\frac{h_0}{2} + \Sigma h + \frac{h_n}{2}\right)$$

Simpson's One-third Rule:

This rule is based on the assumption that the curve joining the ends of any three successive offsets is a parabola. *Caution:*

The area must be divided into an even number of strips equally spaced, and the first (end) offset is to be numbered zero.

$$\text{Area} = \frac{d}{3}(h_0 + 2\Sigma h_{\text{even}} + 4\Sigma h_{\text{odd}} + h_n)$$

d = distance between offsets

h_0 and h_n = end offsets

Σh_{even} = sum of all the even-numbered offsets.

Σh_{odd} = sum of all the odd-numbered offsets.

Problems

27. Determine the number of acres in a square whose sides are (*a*) 541 chains (Gunter's) long; (*b*) 2,272 meters; (*c*) 685 feet.

28. If a parallelogram has its base equal to 645 feet and its altitude equal to 89 feet, what is its area in acres?

29. If a field contains 24 acres and is in the shape of a parallelogram whose altitude is 500 feet long, and if a five-acre field is to be cut off one side, its shape to be a parallelogram with the same altitude, what would be the length of its base?

30. A triangle has two sides 740 and 592 feet long, respectively; the included angle is 35°10′. What is the area, in acres, of the triangle?

31. If the three sides of a triangle are as follows: 442, 790, 598 feet, what is its area (*a*) in acres; (*b*) in hectares?

32. What is the area of a trapezoid whose two parallel sides are 80 and 125 feet long and whose altitude is 72 feet (*a*) in square feet; (*b*) in acres?

33. Find the area (*a*) in square feet; (*b*) in acres; of a trapezium the dimensions of which are as follows (refer to Fig. 60): a equals 200 feet; b equals 153 feet; angle F is 150°30′; the area of triangle 2 is 4 acres.

34. Find in acres with both formulæ the area of the figure shown in Fig. 62, using the following values: d equals 10 feet; h_n equals 18 feet. Starting with the first h_0 at the left-hand side, use the following values: 10, 14, 8, 6, 12 feet.

CHAPTER X

LAND SURVEYING

A knowledge of the methods used in making original surveys, of the laws governing the resurveys, and of the general principles of adverse possession is essential to the farmer and landowner in avoiding needless litigation and maintaining his rights.

109. Land surveying is classified according to its object under two distinct headings—original surveying and resurveying.

Original surveys are made for the purpose of mapping and subdividing areas which have never been so divided and establishing monuments thereon. Such surveys should be conducted only by qualified engineers or professional surveyors. The methods used will be discussed under the U. S. System of Surveying the Public Lands (Art. 113).

Resurveys are made for the purpose of relocating previously established landmarks and are not made for the purpose of finding where such landmarks should have been placed. If the original landmarks cannot be definitely located, it is the duty of the surveyor to reestablish such landmarks as near as possible to their original location. In disputed cases, the surveyor has no recognized powers of decision; such cases must be settled in the courts. He may act as an expert witness.

110. Responsibility of the Surveyor.—Surveying is a profession or business. An engineer is recognized as qualified in his profession and may be held liable only for negligence and fraud. Failure to exercise reasonable care and skill constitute negligence.

A surveyor is not necessarily recognized as qualified; he, therefore, assumes the added responsibility of guaranteeing his skill and may be held liable for negligence and fraud and, also, for lack of skill. All maps, survey notes, or other data obtained by a surveyor while in the employ of an individual, city, state, or corporation are the property of the employer. A city engineer or a county surveyor has no ownership rights in notes, maps, or other data which he or his assistants prepare or obtain in the discharge of official duties.

All maps, survey notes, or other data obtained by a consulting or independent engineer in preparation of a report or plan for a client are the property of the engineer. The client, in this case, is entitled only to the finished report or plan.

111. Methods of Land Subdivision.—There are two methods of land subdivision in use in the United States. One is known as *metes and bounds;* the other is the *U. S. system of surveying the public lands.*

112. Metes and Bounds.—Previous to 1784, the method of metes and bounds, which is a particular method of land description, was in use. The rectangular system being then unknown, any parcel of land was made dependent for identification upon a written description of its measurements and boundaries; hence, the expression *metes and bounds.* Very large areas of the United States, including all the eastern portions and Kentucky and parts of Michigan, Illinois, Indiana, Missouri, Louisiana, California, and Texas were surveyed in this manner, and the method is still in force in these areas. The method of metes and bounds is highly important, therefore, at the present time. Unfortunately, many of the descriptions in existing deeds are hardly worthy of the name, and much care, ingenuity, patience, and skill are necessary for the proper interpretation of such deeds.

113. U. S. System of Surveying the Public Lands.—The method now used to survey public lands in the United States is laid down by law. This system was inaugurated by an Act of Congress, in 1784, and has been subsequently modified by further acts of Congress. The following quotation from the *Manual of Surveying Instructions for the Survey of Public Lands of the United States and Private Land Claims* gives a description of the method used:

> Existing law requires that, in general, the public lands of the United States "shall be divided by north and south lines run according to the true meridian, and by others crossing them at right angles so as to form townships 6 miles square and that the corners of the township thus surveyed" must be marked with progressive numbers from the beginning.
>
> Also that the townships shall be subdivided into 36 sections, each of which shall contain 640 acres, as nearly as may be, by a system of two sets of parallel lines, one governed by true meridians, and the other by parallels of latitude, the latter intersecting the former at right angles, at intervals of a mile.

In the execution of the public surveys under existing law, it is apparent that the requirements that the lines of survey shall conform to true meridans and that the townships shall be 6 miles square, taken together, involve a mathematical impossibility due to the convergency of the meridians.

Therefore, conform the meridional township lines to the true meridians produces townships of a trapezoidal form which do not contain the precise area of 23,040 acres required by law, and which discrepancy increases with the increase in the convergency of the meridians, as the surveys attain the higher latitudes.

In view of these facts, and under the provisions of Sec. 2 of the Act of May 18, 1796, that sections of a mile square shall contain 640 acres, as nearly as may be, and also under those of Sec. 3 of the Act of May 10, 1800, that "in all cases where the exterior lines of the townships, thus to be subdivided into sections or half sections, shall exceed, or shall not extend to six miles, the excess or deficiency shall be specially noted and shall be added to or deducted from the western or northern ranges of sections or half sections in such townships, according as the error may be in running lines from east to west or from south to north; the sections and half sections bounded on the northern and western lines of such townships shall be sold as containing only the quantity expressed in the returns and plats, respectively, and all others as containing the complete legal quantity," the public lands of the United States shall be surveyed under the methods of the system of rectangular surveying, which harmonizes the incompatibilities of the requirements of the law and practice, as follows:

First.—The establishment of a principal meridian conforming to the true meridian and, at right angles to it, a base line conforming to the parallel of latitude.

Second.—The establishment of standard parallels conforming to parallels of latitude, initiated from the principal meridian at intervals of 24 miles and extended east and west of the same.

Third.—The establishment of guide meridians conforming to true meridians, initiated upon the base line and successive standard parallels at intervals of 24 miles, resulting in tracts of land 24 miles square, as nearly as may be, which shall be subsequently divided into tracts of land 6 miles square by two sets of lines, one conforming to the true meridians, crossed by others conforming to parallels of latitude at intervals of 6 miles, containing 23,040 acres, as nearly as may be, and designated *townships*.

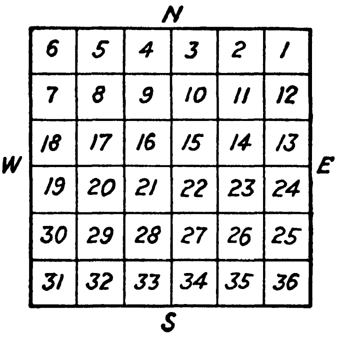
Such townships shall be subdivided into 36 tracts, called *sections*, each of which shall contain 640 acres, as nearly as may be, by two sets of parallel lines, one set parallel to a true meridian and the other conforming to parallels of latitude, mutually intersecting at intervals of 1 mile and at right angles, as nearly as may be.

Any series of contiguous townships or sections situated north or south of each other constitutes a *range*, while such a series situated in an east and west direction constitutes a *tier*.

By the terms of the original law and by general practice, section lines were surveyed from south to north and from east to west, in order uniformly to place excess or deficiency of measurement on the north and west sides of the townships. But under modern conditions many cases arise in which a departure from this method is necessary. Where the west or the north boundary is sufficiently correct as to course, to serve as a basis for rectangular subdivisions, and the opposite line is defective, the section lines should be run by a reversed method.

For convenience, the well-surveyed lines on which subdivisions are to be based will be called *governing boundaries* of the township.

The tiers of townships will be numbered, to the north and south, commencing with No. 1, at the base line; and the ranges of the townships, to the east or west, beginning with No. 1, at the principal meridian of the system.



6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Fig. 63.—Numbering townships.

The 36 sections into which a township is subdivided are numbered (see Fig. 63) commencing with No. 1 at the northeast angle of the township, and proceeding west to No. 6, and thence proceeding east to No. 12 and so on, alternately, to No. 36 in the southeast angle. In all cases of surveys of fractional townships, the sections will bear the same numbers they would have if the township was full; and where doubt arises as to which section numbers should be omitted, the proper section numbers will be used on the side or sides which are governing boundaries, leaving any deficiency to fall on the opposite sides.

Standard parallels (formerly called *correction lines*) shall be established at intervals of 24 miles, north and south of the base lines, and guide meridians at intervals of 24 miles, east and west of the principal meridian, thus confining the errors resulting from convergence of meridians and inaccuracies in measurement within comparatively small areas.

114. Sections Subdivisions.—Sections are divided into half-sections (320 acres), quarter-sections (160 acres), half-quarter sections (80 acres), quarter-quarter sections (40 acres), or even smaller subdivisions.

In the rectangular system, land description is accomplished by referring to its location in the particular township of which it is a part. Thus, in the accompanying Fig. 66, the north half of the S.W.¼ would be described as

. . . the north half, of the southwest quarter, Sec. 36, township 12, north, range 12 west, containing 80 acres more or less according to the government survey thereof, all situated in Mate County, state of Mississippi.

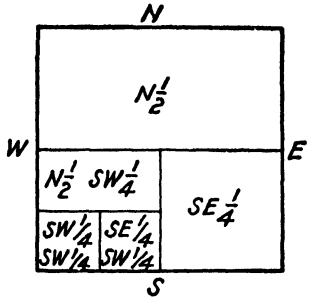


Fig. 64.—Describing parts of a section.

All confusion is avoided by this system. The description of the various divisions of a section can best be studied by referring to Fig. 64, which shows sufficient information to enable the student to make a description of any subdivision that may be necessary.

115. Corners and Monuments.—Various kinds of monuments were used to mark corners in original surveys, these differing with the locality of the land and with the importance of the corner. In rough, rocky country, piles of stones were used. In timbered sections, posts are available and were commonly used. It sometimes happens that a corner site is occupied by a tree, and whenever this was the case the tree was marked and left as a monument. In prairie country, a mound of earth was built over the corner, and in the center was placed an object of permanent character; or oftentimes a pit marked a corner.

It is to be regretted that corners were not made of a more permanent character. Pits are soon filled up, mounds washed down, posts rot off at the ground, and stone piles are easily moved.

When corners and lines are relocated by a survey, concrete monuments should be set to mark them, in order to render them permanent. The landowners can well afford the expense of making these monuments. A concrete post 6 or 8 inches square which extends into the ground 4 or 5 feet and shows above the ground 1 foot with a 1-inch bolt embedded in the top to mark the center is an adequate method of marking corners, while points along the boundary lines may be marked with smaller concrete posts set at intervals.

To obtain information regarding the location of the corners and the bearing of the section lines, the records at the county courthouse should be consulted. Here the notes taken at the time of the original survey will be found. These will tell where the corners were located, how marked, with description of *bearing trees* (B.T.) if any were used, and give the bearings and length of lines run.

116. Significance of Markings.—All marks and monuments established by an original survey and recorded on the written deed description are accorded the highest degree of authority in any subsequent transactions concerning the land. The deed description of bearings, length of lines, etc., may differ from the bearings and distances as determined by the monuments, but the latter rank first in authority. Established monuments control absolutely; therefore, the importance of relocating established marks and monuments in resurveying work cannot be too strongly emphasized.

117. Witnessing Corners.—When establishing a corner, it is good general practice, and often desirable in order to facilitate the relocating of the corner, to use nearby objects of a character as permanent as possible for witness marks. These objects should be readily observable by any person endeavoring to find the actual corner and should be so marked that the observer may readily locate the corner by reference to the markings. In some cases, it is impracticable to set a corner of permanent character—for instance, where the corner location occurs in a stream. In such cases, witness corners bearing the letters W.C., in addition to the necessary reference markings, are set on the lines of the corner. These witness corners are also witnessed by nearby objects of permanent character as before. In timbered sections, a corner is often conveniently witnessed by bearing trees standing close to the corner.

The bearing of the tree and its distance from the corner is first determined, then the tree is blazed on the side facing the corner by taking off the bark from a short section of the trunk. The reference markings are then cut on the exposed surface of the tree. Abbreviations are used in markings, thus:

R 12 W
T 16 N
S 36
B T
'⟍ 14′ N 11 E

which would be read "Range 12 west, township 16 north, Sec. 36. Bearing tree, corner is distant 14 feet, north 11° east."

118. Adverse Possession.—Title to land may pass through the operation of the doctrine of adverse possession. This law was enacted about the time of King James I and was found necessary in order to avoid congestion of the courts in settling claims to a title in land under the old common law which held that the owner of land could not lose his title to same. Much chicanery and malpractice was resorted to by imposters under the operation of this old law. The doctrine of adverse possession as it now obtains holds that if a person owning land leaves or abandons it for a certain period, which is statutory (in most states, the period is 20 years), he loses his title to the person or the descendant of the person who has continuously occupied the land for the statutory period, provided such occupation has been openly hostile and adverse to the original owner's title.

119. Deeds.—Title to land may be transferred in various ways. Title by adverse possession has already been discussed. Title by deed is by far the most common method of transfer, though land may also change owners through the operation of law, as by an exercise of the right of eminent domain, by act of dedication, or by rights of accretion.

120. What Constitutes a Deed.—The essentials of a deed are given by Tucker as follows:

> To be valid and binding a deed of land must contain the essential elements of a contract. The following must also be true:
>
> There must be
> Sufficient writing.
> Proper parties.
> A thing to be granted or conveyed.
> A sufficient consideration and a proper and sufficient execution of the instrument, *i.e.*, it must be signed, sealed, attested, and acknowledged.
> A good delivery and acceptance—the mere writing alone is not operative unless coupled with delivery by one party and acceptance by the other.

The title is not perfected in the recipient of the deed (save as between the parties) until the deed is engrossed upon the registry of deeds for the county in which the land lies.

121. Kind of Deeds.—There are three kinds of deeds—warranty, sheriff's, and quit claim.

122. Warranty Deed.—This is the most desirable form of deed. While there are many particular items that may be specifically warranted in a deed, the seller of land in giving a warranty deed to same guarantees his perfect right to convey same, also that there are no blots on the title or, in other words, that there are no unsatisfied mortgages or other burdens upon the land (except any mentioned specifically in the deed). He also warrants the title; that is, he guarantees that he or his heirs will defend the title should legal claims against same be made. The title to land is becoming increasingly important, and every precaution is taken to safeguard same; therefore, the buyer of land should not complete the transaction before having an abstract of title made. Many lawyers make a specialty of this branch of their profession. The buyer of land should place the deed in the hands of such a lawyer, who proceeds to examine in minute detail the past history of the land described and traces the clear title back to the original deed from the government to the first owner of the land. The lawyer then states his opinion in writing regarding the degree of ownership of which the present holder of the land is possessed, together with a record of all transfers, which is, of course, a clear indication to the buyer as to the value of the title.

123. Sheriff's Deed.—This deed is given on lands sold at delinquent tax sales. Such lands are usually purchased at low prices, and after a certain lapse of time, which differs in various states, a sheriff's deed is issued for the land, provided that the delinquent owner has not meanwhile come forward to claim possession and reimbursed the present holder for all money paid out, including interest thereon.

124. Quit-claim Deed.—This deed carries no element of warranty whatsoever. The seller merely transfers to the buyer any rights to the land of which he may be possessor. The old established rule "Let the buyer beware" is applicable to such transfers. Many frauds have been perpetrated through the use of such deeds.

To be fully valid, all transfers of real property must be recorded on the register of deeds in the county or counties in which the land is situated. In the files of the registrar is kept an exact duplicate of all deeds registered. These copies may at any time be examined by any person interested. The lawyer abstracting a title makes frequent use of this privilege. A grantor and a grantee index of the duplicates is maintained. All that is necessary for a person wishing to look up a recorded deed is the name of one or both of the parties to the deed in question and the approximate date of the transfer; these being known, a visit to the registry of deeds for the county and an inspection of the proper index will reveal the book and page number on which a duplicate is recorded. From the latter the desired information may be obtained.

125. Relocating Lost Corners.—In the passage of time, corner monuments may be lost or obliterated. The following distinction between the two conditions is made by the General Land Office.

> A *lost* corner is one whose position cannot be determined beyond all reasonable doubt, either from original marks or reliable external evidence.
>
> An *obliterated* corner is one where no visible evidence remains of the work of the original surveyor in establishing it. Its location may, however, have been preserved beyond all question by acts of landowners and by the memory of those who knew and recollect the true situation of the original monument.

To relocate an obliterated corner, all the available evidence must be collected (due regard must be paid to what is actually evidence and what is merely opinion). Evidence would be presented in the case of a tree stump's being positively identified as the stump of the bearing tree witness to the corner or by the statement of a witness to the effect that a certain available mark was established a certain definite distance from the corner and at right angles to it.

The true situation of the corner is then determined by the evidence collected.

To relocate a lost corner, the lines must usually be rerun as nearly as possible on the original lines. As stated previously in this chapter, the aim is not properly to locate the corner but to locate it in its original position. Whether that position is the correct one or not has no bearing on its relocation.

The Department of the Interior, General Land Office, Washington, D. C., issues, free of charge, a circular on the "Restoration of Lost or Obliterated Corners," from which the following excerpts are taken.

> General rules: The boundaries of the public lands established and returned by the duly appointed government surveyor, when approved by the surveyors general and accepted by the government, are unchangeable.
>
> The original township, section, and quarter section corners established by the government surveyors must stand as the true corners which they

are intended to represent, whether the corners be in the place shown by the field notes or not.

Quarter-quarter corners not established by the government surveyors shall be placed on the straight lines joining the section and quarter section corners and midway between them, except on the last half mile of section lines closing on the north and west boundaries of the township, or on other lines between fractional sections.

All subdivision lines of a section running between corners established in the original survey of a township must be straight lines, running from the proper corner in one section line to its opposite corresponding corner in the opposite section line.

In a fractional section where no opposite corresponding corner has been or can be established, any required subdivision line of such section must be run from the proper original corner in the boundary line as nearly due east and west, or north and south, as the case may be, to the water course, Indian reservation, or other boundary of such section, as due parallelism to section lines will permit.

The subject of magnetic declination or variation, formerly deemed most important in the surveys, is mentioned only to advise against its use as a basis for the location of any lost line, though it may be a temporary guide in a preliminary search for old evidences. Its importance is greatly overrated, from lack of knowledge of the actual practice of surveyors, in the days when both their instruments and their knowledge were more primitive.

Lost or obliterated standard corners will be restored to their original position on a base line, standard parallel, or correction line by proportionate measurements on the line, conforming as nearly as practicable to the original field notes and joining the nearest identified original standard corners on opposite sides of the missing corner or corners.

The term *standard corner* will be understood to designate standard township, section, quarter section, and meander corners, and, in addition, closing corners in the following cases: Closing corners used in the original survey to determine the position of a standard parallel, or established during the survey of same, will, with the standard corners, govern the alignment and measurements made to restore lost or obliterated standard corners but not others; closing corners will not control in any manner the restoration of standard corners on a base line or standard parallel.

A lost or obliterated closing corner from which a standard parallel has been initiated or to which it has been directed will be reestablished in its original place by proportionate measurement from the corners used in the original survey to determine its position. Measurements from corner on the opposite side of the parallel will not control in any manner the restoration of said corner.

A missing closing corner originally established during the survey of a standard parallel, as a corner from which to project surveys south, will be restored to its original position by considering it a standard corner and treating it accordingly.

Therefore, paying attention to the preceding explanations, we have for the restoration of one or several corners on a standard parallel, and for general application to all the other surveyed lines, the following proportion:

As the original field note distance between the selected known corners is to the new measure of said distance, so is the original field note length of any part of the line to the required new measure thereof.

The sum of the computed lengths of the several parts of a line must be equal to the new measure of the whole distance.

126. Rerunning Old Survey from a Deed.—This branch of surveying is somewhat similar to the relocation of lost corners, but here the effort is magnified by the necessity of locating all the original boundaries of the property under investigation. Visible evidence of established marks or monuments is of first importance, since they establish beyond all doubt the exact original location. It sometimes happens that most careful searching fails to bring any such visible evidence to light, and recourse must then be had to the written description of boundaries in the deed. If, as was formerly the custom, the direction of boundaries is defined in the deed by their magnetic bearings, the declination of the needle at the time of the original survey must first be determined. Often this declination angle is not given in the deed, in which case the data compiled by the U. S. Coast and Geodetic Survey will be of material assistance in computing the approximate value of this angle. The compilation referred to consists of a very complete list of declinations for many parts of the United States. The change in declination since the date of the original survey must then be determined, and the magnetic bearings corrected to date.

If one of the original lines can be established by marks of the old survey, the present bearing of that line can be determined, and a comparison of the present with the original bearing will reveal the change in declination. Interior angles may be computed from the bearing given in the deed and turned off on the transit in their proper order from the single reestablished line. If more than one of the old boundaries can be identified, a comparison of the results obtained by using each as an initial line from which to turn off the angles will give some idea of the accuracy of the original survey.

Where the records of the survey in question are found to be either insufficient or inconsistent, valuable aid may be secured by examining the records of old deeds to adjoining lands at the register-of-deeds office or, sometimes, at the office of the city or county clerk.

Problems

35. The student should determine in what township his home town is located.

36. Describe the parts of a section in Fig. 65 as Nos. 1, 2, 3, 4, and 5.

37. Describe the parts of a section in Fig. 66 as Nos. 1, 2, 3, 4, and 5.

38. Write a warranty deed for the section of land in which your school is located.

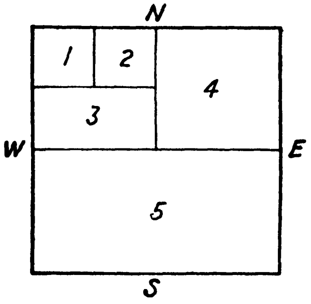


Fig. 65.—Parts of section for problem 36.

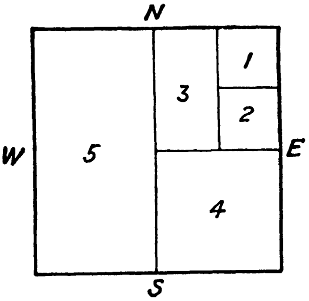


Fig. 66.—Parts of section for problem 37.

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CHAPTER XI

DRAINAGE PROPERTIES OF SOILS

The effect of differences in soil characteristics on drainage is so pronounced as to render a proper presentation of the subject impossible without a review of the more important soil properties.

A classification of soils according to their origin and from a drainage standpoint suggests an arrangement in five general groups, as follows:

1. Residual
2. Glacial
3. Alluvial
4. Cumulose
5. Marine

127. Residual.—Residual soils are those which have usually been formed by the weathering and disintegration of native rocks in place. The destructive action of many natural forces, exerted through countless centuries of time, has resulted in both a physical and chemical decomposition of material which now covers a very large area of the United States, principally in the uplands of the central, south-central, and eastern regions. As the rocks from which such soils are formed differ very widely in mineral composition, a complex variety has been created which is difficult to classify.

In sections of humid climate, the original soil constituency has been materially modified by the leaching out of the more soluble minerals and by accretion of organic matter through successive periods of growth and decay of vegetation. Due principally to oxidation and the formation of iron compounds, the predominant color is red or yellow, and the texture is generally that of fine clay, though sand is also encountered in many localities.

Weathering of glacial and loess or wind-blown material is a secondary modification that has a wide application in certain areas of the country. In fact, loess soils are often included as a major division on account of their great extent, and because of their susceptibility to washing.

128. Glacial.—Thousands of years ago, the entire northern portion of the temperate zone of North America was covered with an immense mantle of ice varying in thickness from a few feet near the edges to a mile or more at its center.

By reason of tremendous internal pressure and under action of gravity, this glacial mass was capable of moving several feet per day, accumulating fragments of rock and detritus on its under side, overriding hills, and gouging out valleys. Great quantities of pulverized material became impregnated under the ice and was carried southward until temperatures were encountered high enough to melt the ice more rapidly than it could advance. A large portion of the imprisoned material was then carried still farther south and there deposited by gushing streams of melting ice. Still larger portions of this detritus was deposited where it lay as the ice cake thawed and the glacier retreated. Most authorities on glaciation now agree that the ice age was not one unbroken invasion and retreat of the ice cap but consisted of five distinct epochs or cycles, the last of which occurred more than 10,000 years ago. This accounts, in part, for the present existence of subsurface stratification or successive layers of pervious and impervious matter which affects so vitally many drainage problems.

It is thought that the ice age was followed by an epoch of aridity, accompanied by strong westerly winds causing large quantities of fine dry detritus to be picked up and transported great distances. In this manner, the formation of the loess soils of the central United States and the adobe soils of the arid Southwest is explained. Not all of the glacial deposit, however, was susceptible of movement in this way. The heavier types have remained in their original positions and are known as *glacial till* or *glacial drift soils*, while still another series of glacial origin is the glacial *lake* formations.

The glacial till soils are characterized, in the main, as heavy clay or clay loams due to the tremendous grinding force that has produced them. The loess, adobe, and lake soils are very rich in quality, of exceptionally good tilth, and respond readily to underdrainage.

129. Alluvial.—As the name implies, *alluvial* soils owe their origin to the eroding and transporting capacity of water. Without going into a detailed discussion, it may be remarked that the power of streams to carry fine silt in suspension and to roll coarser particles along their bottoms depends wholly on the velocity with which the water travels. A slight increase in velocity results in a greatly accelerated transportive ability, and, conversely, if the velocity be checked from any cause whatever, a certain percentage of suspended silt is likely to be deposited. Since the gradient or slope of streams is always much steeper in their upper reaches than it is near their mouths, the rate of travel of water is rapid in the former case and sluggish in the latter. Consequently, in the aggregate, a large quantity of soil is annually cut away from higher lands, carried down by the streams to regions of lower elevation, and here deposited in a thin sheet as the water spreads out over its natural flood plain. The sediment thus deposited is invariably found assorted with heavier particles near the stream bank, and the finer silt farther out, causing a formation with the surface slope away from the watercourse. This is typical of all overflow valleys. That portion of silt which is not disposed of in this way is carried out to sea and there contributed to the gradual raising of the ocean bed. Narrow blankets of alluvia, laid down in the manner just described, are found along practically every stream east of the Rocky Mountains. Alluvial deposits, from a geographical standpoint, are the youngest of all soils; in fact, they are still in the formative stage at the present time, excepting, of course, in those localities where floods are confined between levees.

In point of fertility, such soils are surpassed by none, but the topography of regions in which they occur is generally flat, low, and in need of drainage.

130. Cumulose.—Cumulose soils are those formed by the process of slow oxidation of organic matter under water. They are composed almost entirely of decayed vegetation accumulated in the shallow depressions which occur here and there over the entire country. Any basin which contains stagnant water becomes a receptacle for the formation of cumulose soil. These basins, varying in extent from a few to several thousand acres, were formed, in the main, by glaciation, by stream action (cutting off bends, etc.), and by marshes along lake shores and seacoasts. The familiar swamp is cumulose in character, for it is here that water-loving plants and grasses grow luxuriantly, then wither and are submerged. This process is continued year after year, until, in time, layers are formed of sufficient depth to support great forests.

Other common names for soils of this type are *peat* and *muck*, the difference between which is only one of degree. As the process of decay sets in, the substance is known as peat as long as it is possible to distinguish the original stem and leaf structure, while, thereafter, as putrefaction becomes more complete, the peat merges into muck. Very often, the pure organic character of such soils is adulterated by the inwash of minerals in solution. When relieved of their surplus water and allowed to settle, soils of the cumulose type never fail to provide fertility of the highest order.

131. Marine.—Along the entire Atlantic and Gulf seaboard in the eastern and southeastern portions of the United States, there is a wide stretch of territory which Nature has reclaimed from the ocean. This soil is derived from the older residual types to the west and north and has originated partly by a vast upheaval, in some prehistoric age, of the ocean's bed. Owing to long-sustained agitation by waves, marine soils occur in relatively large, well-rounded particles, such as sand and sandy loam, the coarse texture of which permits easy underdrainage where adequate outlets can be secured. Though saline in character near the coast line and of flat topography, these soils, when drained, are capable of supporting a wide range of diversified crops. The Everglades section of Florida is, perhaps, the most striking example of this and of the cumulose type.

132. Mechanical Composition.—The manner in which soils will react to treatment by drainage depends very largely upon their mechanical composition or the size and gradation of the individual grains. This range of sizes determines the *texture* of a soil and gives rise to the familiar classification into sand, loam, clay, etc. Arbitrary limits have been established by the U. S. Bureau

TABLE 10.—SOIL SEPARATES

Separate	Diameter of Grains, Millimeters
Fine gravel	2.0 –1.0
Coarse sand	1.0 –0.5
Medium sand	0.5 –0.25
Fine sand	0.25 –0.10
Very fine sand	0.10 –0.05
Silt	0.05 –0.005
Clay	0.005–0.00

(1 millimeter = 0.03937 inch.)

of Soils for the size range in each class and termed *soil separates* in order to distinguish them from the ordinary names for each group. In other words, clay, loam, sandy loam, etc., as commonly found in their natural state, contain a variable mixture of soil separates which can be determined by sieve analysis. The limits of grain diameter set for each soil-separate group, with the corresponding names as adopted by the Bureau of Soils, are given in Table 10.

133. Soil Classification.—Soils may be classified in a number of ways, but the following taken from the *U. S. Bureau of Soils Bulletin* 96, describes the method used by that bureau in classifying soils in the United States:

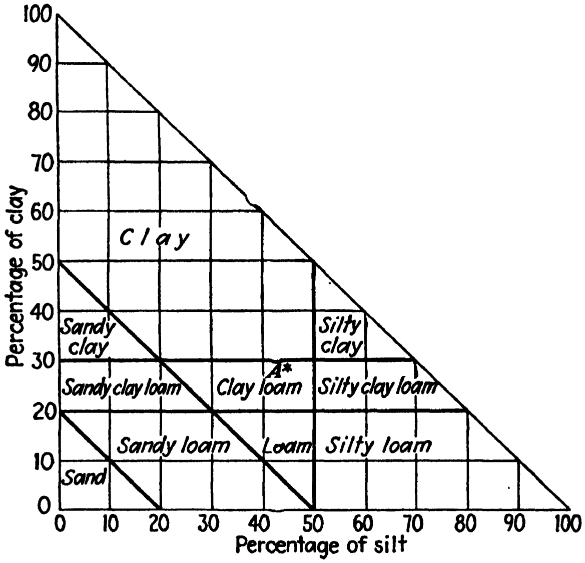

FIG. 67.—Right-angled texture chart for classifying soils.

> The soils are brought together into groups on the basis of certain characteristics of the soils themselves, each group constituting a series. A *soil series* may be defined, therefore, as a group of soils having the same range in color; the same character of subsoil, particularly as regards color and structure; broadly, the same type of relief and drainage; and a common or similar origin (*i.e.*, Wooster series, Olympic series, etc.).
>
> Soils may be grouped on the basis of texture also, and a group of soils all having the same texture belong to the same class. A *soil class*, therefore, includes all soils having the same texture, such as sands, clays, loams, etc.

A soil generally contains particles of various sizes giving it a certain texture, and the question is, what percentage of the given separates determines how the soil shall be classified. The use of a right-angle soil texture chart (Fig. 67) enables the student to classify soils readily. A "trilinear" (equilateral triangle) chart has been much used recently, but it is more difficult to read. The same values are obtained with both charts.

Example.—*A* soil contains:

28 per cent clay
45 per cent silt
27 per cent sand (by difference)

This may be located as point *A* in Fig. 67, and its classification found to be clay loam.

Translating the chart into tabular form, the values are given in Table 11.

TABLE 11.—CLASSIFICATION OF SOILS

Class	Sand, per cent	Silt, per cent	Clay, per cent
Sand	80 to 100	0 to 20	0 to 20
Sandy loam	50 to 80	0 to 50	0 to 20
Loam	30 to 50	30 to 50	0 to 20
Silt loam	0 to 50	50 to 100	0 to 20
Sandy clay loam	50 to 80	0 to 30	20 to 30
Clay loam	20 to 50	20 to 50	20 to 30
Silty clay loam	0 to 30	50 to 80	20 to 30
Sandy clay	50 to 70	0 to 20	30 to 50
Clay	0 to 50	0 to 50	30 to 100
Silty clay	0 to 20	50 to 70	30 to 50

The average percentage of separates present in soils as they commonly occur is shown in Table 12, which is taken from *Bulletin* 50 of the Engineering Experiment Station, Iowa State College.

134. Colloids.—Nearly all soils contain a certain proportion of jelly-like material composed of submicroscopic particles called *colloids*. Any particle whose diameter is less than 1 micron (0.001 millimeter) would come under this classification. Although in the early days of soil science it was recognized that this jelly-like material influenced the properties of soils to a marked degree, its action was not well understood, and only in recent years has it received the serious attention of scientific investigators. The

TABLE 12.—PHYSICAL COMPOSITION OF COMMON SOILS[1]

Soils	Percentage of separate present							Pore space	Number of grains in 1 gram, millions	Surface area of 1 cubic foot, square feet
	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay			
Coarse sand	5.0	13.0	27.0	30.0	11.0	8.5	5.5	40.0	3,276	40,500
Medium sand	5.0	13.0	20.0	32.5	14.0	9.0	6.5	41.8	3,956	44,500
Sandy loam	5.0	10.0	11.0	26.0	11.0	22.0	15.0	51.0	6,485	66,600
Fine sandy loam	2.0	2.5	5.0	20.0	27.5	32.0	11.0	50.0	4,902	62,000
Silt loam	1.0	1.5	2.5	6.0	11.0	56.0	22.0	53.0	9,639	104,000
Clay loam	3.0	5.0	5.0	12.0	10.0	28.0	37.0	54.0	16,371	136,000
Clay	0.0	2.0	2.5	5.5	7.0	37.0	46.0	56.0	19,525	142,000

[1] Compiled from data given in "Principles of Soil Management," Lyon & Fippin.

name given to this material has undergone a process of evolution as its nature has become better understood. In 1850, it was known as a "zeolite" or "zeolite-like substance," later as "argile colloidale," "true clay substance," or "clayite"; more recently, as Van Bemmelen's absorption compounds of a jelly-like nature or as the "clay complex"; and, finally, as *colloidal material* or *colloids*. Just what function colloidal material performs in soil composition and the degree to which it affects soil behavior are still matters for further investigation to disclose.

135. Effective Diameter.—In order to measure the influence of texture in certain soil phenomena, the attempt has been made

TABLE 13.—PROPERTIES OF COMMON SOILS[1]

Kind of soil	Effective size of soil grains, millimeters	Percentage of pore space	Surface area of 1 cubic foot of soil grains, square feet
Finest clay soil	0.004956	52.94	173,300
Fine clay soil	0.008612	48.00	110,500
Heavy red clay soil	0.01111	44.15	91,960
Loamy clay	0.02542	49.19	70,500
Clayey loam	0.01810	47.10	53,490
Loam	0.02197	44.15	46,510
Sandy loam	0.03035	38.83	36,880
Sandy soil	0.07555	34.45	15,870
Coarse sandy soil	0.1432	34.91	8,381

[1] After KING.

to express differences in texture by means of effective diameters. That is, after making an analysis to determine the range of sizes of grains and the pore space in a given sample, the effective diameter is said to be that diameter which would yield the same percentage of pore space if all the soil grains were replaced by others of uniform and "effective" size. It is also defined as the diameter of the grain which has 10 per cent of the grains smaller and 90 per cent larger than itself. Nearly all formulæ for the flow of water through soils make use of this relationship and require the effective diameter to be determined.

136. Soil Structure.—Nothing has been said so far about the well-known tendency of soil grains to cling together and form clusters or crumbs. Such a condition is termed the *structure* of a soil, and the purpose of plowing, cultivation, and other agricultural treatment is to maintain between the soil particles a good structural relation. Soil is said to be *in good tilth* when in the proper structural condition. As will appear later, the moisture content of a soil is responsible for and determines to a very large extent the kind of structure it has.

137. Porosity.—The porosity or percentage of pore space is thus seen to depend upon both size and gradation of individual particles (texture) and upon the manner in which they are arranged in groups or clusters (structure). A theoretical arrangement of round grains by W. J. Schlick is given in Fig. 68, which shows quite clearly some ideal possibilities and the corresponding effect on the percentage of pore space. It is important to observe that, whereas the porosity of groups 1 and 2 is exactly the same, the resistance to a movement of air or water is much greater in 2 on account of the smaller size of the pores and their more indirect connection.

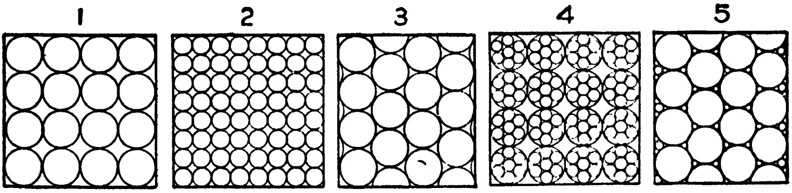

FIG. 68.—Ideal arrangement of spherical soil particles. (1) and (2), columnar order, 47.64 per cent of pore space; (3) oblique order, 25.95 per cent of pore space; (4), compound spheres in oblique order, 74.05 per cent of pore space; (5), three sizes of spheres with closest packing, about 5 per cent of pore space.

A study of Fig. 68 will explain why the finest clay soil reported in Table 12 contains an amount of pore space 65 per cent greater than sandy soil with nearly eleven times as much surface area in 1 cubic foot of grains. Consequently, the theoretical reason for a practical fact is here supplied, *i.e.*, that water will pass more freely through sandy soil than it will through clay.

138. Permeability.—Friction, or resistance to the flow of water, depends, to a great extent, on the area of rubbing surface between the water and sides of the channel through which it passes. The size and interrelation of pores are, therefore, of far greater importance to freedom of movement than is their total volume. Thus, if *permeability* be defined as the ease with which water passes through a given soil, it is seen to vary (in common soils) inversely with the percentage of pore space. Strange as it may seem, a porous soil is, strictly speaking, generally the most compact and impervious. Texture and structure, then, are the two factors that determine the size and accessibility of pores and govern the extent of soil porosity and permeability. Texture in a given soil is quite constant and not easily subject to change, but the structure of a soil may be modified and improved with great ease by intelligent treatment.

139. Soil Moisture.—The capacity of soils to hold moisture bears a very close relation to their textural and structural characteristics, though it is difficult if not impossible to test this capacity without destroying their original structure. In fact, practically all laboratory tests of soils deal only with the size and gradation of individual particles and take no account of the probable grouping into clusters of such particles in their natural condition. Whenever a soil is saturated with water for a considerable period of time, it becomes "puddled," and any structure it may have possessed is broken down. Results are useful, however, because when the texture of a soil is known, it is possible to predict its probable structural character with considerable accuracy.

For greater convenience in studying its behavior, soil moisture is commonly divided into three forms—hygroscopic, capillary, and gravitational.

Hygroscopic.—Hygroscopic moisture is the least important from a drainage standpoint, because it is in too close affinity with the soil grains to be available for plant life. It can be driven out only by the application of heat to a soil which, upon cooling, immediately reabsorbs its normal quota from the air. In other words, soil, such as dust, which is apparently quite dry, still contains hygroscopic moisture, in an amount dependent upon its porosity and upon the temperature and relative humidity of the surrounding atmosphere.

Capillary.—Capillary or film moisture is that which clings to each soil grain in the form of a thin film. It surrounds each individual particle or group of particles and is held by surface tension against the pull of gravity, a fact which enables it to move in any direction from a wet to a drier spot. The amount present in a given soil depends upon the film thickness (limited by the ultimate strength of the force of tension), the size and arrangement of grains, and the availability of a replenishing supply. The best structural conditions prevail when the capillary-moisture content is just right, and this also determines the proper time to work the soil. All plants take their food in liquid form, and capillary water is the only kind that their root systems can assimilate.

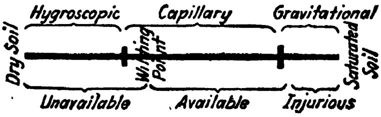

FIG. 69.—Proportional amounts of three forms of soil moisture.

Gravitational.—As the name implies, *gravitational water* is that which is free to obey the laws of gravity. If there be more than enough water to saturate a soil to its maximum capillary capacity, the excess will lie in the pores and gradually work its way downward to an outlet, or else it will accumulate until all the pores are entirely filled and the soil becomes supersaturated or puddled. In such a condition, the granulation of particles is destroyed, air is driven out of the pore spaces, and vegetation, after a time, is suffocated and drowned. Obviously, the most favorable conditions occur when the soil grains are crumby and friable and are holding as much capillary moisture as possible, while the spaces between are filled with warm, moist air. These conditions are brought about only when the surplus gravitational water has a chance to escape into a permeable subsoil or, failing that, into drains placed in the subsoil for this purpose.

A conventional diagram frequently used to illustrate the three forms of soil moisture and their effect upon plant life is shown in Fig. 69.

140. Wilting Coefficient.—The extraction of water by plants becomes increasingly difficult as the capillary supply is reduced, until a point is finally reached where vegetation wilts and dies from lack of moisture. The percentage of moisture contained in the soil at this point is called the *wilting coefficient.* It contains all the hygroscopic moisture present plus a small amount of capillary water which clings too tightly for plants to dislodge. Growing crops, therefore, depend for their life upon the moisture content of soils, which should never fall below the wilting point or be increased much above the capillary capacity, except temporarily.

Table 14, which has been compiled from the data of a number of investigators, indicates the affinity of the various soil types for the different kinds of moisture.

It appears from this table that the gravitational capacity shown for the various soils represents the maximum amount of water that underdrains will ever be called upon to remove. Thus, for sandy loam, 15.3 per cent of 82 pounds or 12.5 pounds of water will need to be collected and carried away from each cubic foot of soil. Assuming that perfect drainage is required to a depth of 4 feet, this is equivalent to removing a sheet of water nearly 10 inches deep over the surface.

TABLE 14.—PERCENTAGE BY WEIGHT OF THE MAXIMUM MOISTURE CAPACITIES OF SOILS

Type of soil	Weight, pounds per cubic foot	Hygroscopic capacity	Wilting coefficient	Capillary capacity	Available capacity	Gravitational capacity	Total capacity
Coarse sand	81	1.0	1.5	13.0	11.5	19.0	33.0
Fine sand	82	2.1	3.3	14.0	10.7	17.9	34.0
Sandy loam	82	4.7	7.0	15.0	8.0	15.3	35.0
Fine sandy loam	83	6.9	10.8	16.0	5.2	14.1	37.0
Loam	83	9.1	13.4	18.0	4.6	10.9	38.0
Silt loam	83	11.8	15.0	19.0	4.0	9.2	40.0
Clay	68	13.2	16.5	20.0	3.5	8.8	42.0
Muck soil	15	*X*	....	250.0	....	83.0	333.0

X, included in capillary capacity.

The height to which water will rise in dry soils of different textures during different periods of time is indicated in Table 15. Usually the rate of rise is slower in fine-textured soils but the ultimate height, over a long time period, is much greater than is the case in coarser soils. Rapid progress is being made at present (1939) by soil scientists toward explaining some of these complex relationships on a basis of variations in pressure.

TABLE 15.—HEIGHT IN INCHES OF RISE OF WATER IN DRY SOILS OF DIFFERENT TEXTURE

Soil	Time							
	Minutes	Hours		Days				
	15	1	2	1	3	8	13	19
Silt and very fine sand	2.7	4.7	7.0	20.0	30.0	45.0	52.0	56.0
Very fine sand	7.6	10.0	12.4	21.0	23.0	26.0	27.5	28.5
Fine sand	9.0	9.5	10.0	11.6	13.0	14.3	15.2	16.0
Coarse and medium sand	5.8	6.0	6.3	7.5	9.0	10.0	11.5	12.5
Fine gravel	4.0	5.0	5.3	6.4	8.0	9.0	10.0	10.8

The quantity of water raised above a water table varies as the distance above that source. This is illustrated in the following table:

TABLE 16.—QUANTITY OF CAPILLARY WATER RAISED IN POUNDS PER SQUARE FOOT OF SOIL PER DAY[1]

Soil	Height above source			
	1 foot	2 feet	3 feet	4 feet
Medium fine sand	2.37	2.07	1.23	0.91
Medium clay loam	2.05	1.62	1.00	0.90

This means that with the water table 1 foot below the surface of a medium clay loam, 2.05 pounds of water will rise to the surface (and evaporate). If the water table is 4 feet below the surface of the same soil, only 0.90 pounds of water will reach the surface in 24 hours. This principle is of importance in determining the depth at which to place drain tile.

[1] 19th Annual Report of U. S. Geological Survey.

141. Crop Requirements.—Underdrains will seldom if ever be taxed with a volume of water even approximating 10 surface inches, owing to the fact that a large portion would spill over the surface, some would be evaporated, and a considerable amount would be needed to replenish the capillary supply needed by plants. Growing crops consume an astonishing amount of water for each pound of dry matter produced, but a wide difference of opinion exists among various authorities on the subject as to the exact quantity. The average of figures quoted by a number of agronomists for various crops is as follows:

TABLE 17.—POUNDS OF WATER CONSUMED BY CROPS IN THE PRODUCTION OF 1 POUND OF DRY MATTER

Crop	Pounds of Water per Pound of Dry Matter
Wheat	530
Oats	541
Barley	435
Peas	363
Clover	344
Corn	297
Potatoes	749
Beans	238
Buckwheat	518
Sugar beets	662
Alfalfa	970
Average	513

142. Erodibility of Soils.—A few years ago, H. E. Middleton of the technical staff of the U. S. Bureau of Chemistry and Soils undertook to make complete analyses of the physical and chemical properties of certain soils that had been observed in the field to be erosive and non-erosive,[1] for the purpose of discovering which properties were most significant in explaining erosional behavior.

Three groups of samples were selected as follows: one containing erosive and non-erosive soils of dissimilar texture taken from widely separated localities; one containing two soils of almost identical texture from the same locality but differing greatly in erosional behavior; and one group of three soils from erosion experiment stations, all erosive.

GROUP 1

Erosive—Memphis silt loam and Orangeburg fine sandy loam, both from Mississippi.

Non-erosive—Nipe clay from Cuba, and Aikin silty clay loam from Oregon.

GROUP 2

Erosive—Iredell loam from 14 miles east of Greensboro, N. C.

Non-erosive—Davidson clay loam from 9 miles north of Greensboro, N. C.

GROUP 3

Erosive soils from erosion experiment stations—
Cecil fine sandy loam, Raleigh, N. C.
Shelby loam, Columbia, Mo.
Miles clay loam, Spur, Tex.

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[1] To conform to the newly adopted terminology of the Soil Conservation Service, read "erodible" for "erosive," and "erodibility" for "erosivity" in the discussion that follows.

Representative samples from various horizons in the profiles of all these soils were subjected to exhaustive physical and chemical tests. Quantitative determinations were made of the following physical properties:

Percentage of sand, silt, and clay
Colloid content (particles smaller than 0.002 to 0.005 mm.)
Moisture equivalent
Lower liquid limit
Maximum water-holding capacity
Specific gravity (weight)
Slaking value
Briquettes at maximum density
  Moisture content
  Apparent specific gravity
  Shrinkage
  Pore space
  Volume of voids
Dispersion ratio
Ratio of colloid to moisture equivalent
Erosion ratio
Ratio of silt to clay

Of all the enumerated qualities only three seemed to have any pronounced correlation with erosional behavior as observed in the field. These were (1) dispersion ratio, (2) ratio of colloid to moisture equivalent, and (3) erosion ratio. Since erosion ratio is a simple function of the other two ratios, in reality the three qualities to be determined by test are moisture equivalent, colloid content, and dispersion ratio.

It is apparent from a study of Table 18 that the dispersion ratio decreases as the resistance to erosion increases and is therefore a fairly consistent measure of erosional behavior, regardless of other properties. On the other hand, the colloid–moisture-equivalent ratio increases as the resistance to erosion increases. Since the dispersion ratio is a function of the mechanical composition and ease of dispersion of the soil particles, and the colloid-moisture equivalent has some relation to absorptive power and infiltration, a combination of the two seems to give a fairly accurate and complete index of erosional behavior so far as physical soil properties are concerned. Such a combination is represented by the "erosion ratio," which is derived by dividing the dispersion ratio by the colloid–moisture-equivalent ratio. The colloid–moisture-equivalent ratio is, of course, simply the

TABLE 18.—PHYSICAL PROPERTIES OF EROSIVE AND NON-EROSIVE SOILS[1]

Character and sample number		Soil type	Depth, inches	Mechanical analysis			Colloid, per cent	Moisture equivalent, per cent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio
				Sand, per cent	Silt, per cent	Clay, per cent					
				Group 1							
Erosive	1	Memphis silt loam (Miss.)[2]	0–8	11.2	75.4	13.4	14.6	21.5	44.6	0.68	65.2
	2	Memphis silt loam (Miss.)[2]	8–28	6.2	63.0	30.8	32.2	28.6	26.3	1.13	23.3
	3	Memphis silt loam (Miss.)[2]	120–216	5.6	80.3	14.2	12.3	21.7	66.0	.57	115.8
	4	Orangeburg fine sandy loam (Miss.)	0–16	64.0	26.1	9.9	11.6	15.0	39.2	.77	50.9
	5	Orangeburg fine sandy loam (Miss.)	16–72	56.9	20.1	23.0	23.5	17.3	16.9	1.36	12.4
	6	Orangeburg fine sandy loam (Miss.)	72–96	77.4	6.4	16.2	16.5	12.5	29.6	1.32	22.4
	7	Orangeburg fine sandy loam (Miss.)	96–136	97.6	.6	1.8	2.4	2.2	27.0	1.09	24.8
Nonerosive	8	Nipe clay (Cuba)	0–12	20.4[3]	32.5	47.1	65.1	30.4	6.1	2.14	2.9
	9	Nipe clay (Cuba)	12–24	23.4[3]	24.1	62.5	63.7	27.2	5.2	2.34	2.2
	10	Aikin silty clay loam (Ore.)	0–20	11.7	28.8	59.5	52.5	30.3	15.1	1.73	8.7
	11	Aikin silty clay loam (Ore.)	20–40	10.4	23.7	65.9	59.8	30.8	13.4	1.94	6.9

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[1] *U. S. Dept. Agr. Tech. Bull.* 178.

[2] Based on wet volume.

[3] A considerable part consists of concretions.

TABLE 18.—PHYSICAL PROPERTIES OF EROSIVE AND NON-EROSIVE SOILS.—(*Continued*)

Character and sample number	Soil type	Hori-zon	Depth, inches	Mechanical analysis[1]			Colloid, per cent	Moisture equiv-alent, per cent	Disper-sion ratio	Ratio of colloid to moisture equiv-alent	Erosion ratio
				Sand, per cent	Silt, per cent	Clay, per cent					
				Group 2							
Erosive 12	Iredell loam	A^1	0–5	36.2	38.4	16.4	24.7	30.5	19.6	0.81	24.2
13	Iredell loam	A^2	5–10	37.3	45.6	16.4	15.0	18.1	13.0	.83	15.7
14	Iredell loam	B	10–20	11.2	23.9	63.1	63.9	45.9	20.9	1.39	15.0
15	Iredell loam	C	20–27	34.9	28.5	35.2	39.0	38.0	23.5	1.03	22.8
Nonerosive 16	Davidson clay loam	A	0–9	31.9	39.9	23.8	27.3	25.1	13.3	1.09	12.2
17	Davidson clay loam	B^1	9–36	14.0	22.3	60.4	64.8	39.3	6.1	1.65	3.7
18	Davidson clay loam	B^2	36–60	18.5	30.4	50.3	66.5	43.0	6.6	1.55	4.3
19	Davidson clay loam	C	60+	35.4	34.5	29.6	53.8	39.3	10.6	1.37	7.7
				Group 3							
Erosive 20	Cecil fine sandy loam, N. C		0–6	58.0	14.4	25.3	21.1	19.2	28.4	1.10	25.8
21	Cecil fine sandy loam, N. C		6–24	28.4	12.3	58.6	53.9	32.9	9.8	1.64	6.0
22	Shelby loam, Mo		0–7	11.9	61.4	24.3	19.5	23.6	31.0	.83	37.4
23	Shelby loam, Mo		7–24	6.1	49.7	42.5	40.2	32.4	27.6	1.24	22.3
24	Shelby loam, Mo		24–36	14.9	42.3	41.7	37.6	30.4	30.3	1.24	24.4
25	Miles clay loam, Tex		0–8	30.1	33.1	34.0	31.4	25.2	27.4	1.25	21.9

[1] Determinations by L. T. Alexander.

[2] Based on wet volume.

percentage of colloids in the soil divided by the moisture equivalent, which is also expressed on a percentage basis.

In Middleton's studies the dispersion ratio was measured as follows:

> A sample of air-dry soil equivalent to 10 grams of oven-dry soil was placed in a tall cylinder of approximately 1,200 cubic centimeter capacity fitted with a rubber stopper. Sufficient distilled water was added to make the volume 1 liter. The cylinder was closed with a stopper and was shaken end over end twenty times. The suspension was then allowed to settle until a 25 cubic centimeter sample, which was pipetted at a depth of 30 centimeters, consisted of particles of a maximum diameter of 0.05 millimeter. From the dry weight of the pipetted fraction, the total weight of silt and clay in the suspension was calculated. The ratio, expressed in percentage, of the silt and clay so determined to the total silt and clay obtained by mechanical analysis is called the dispersion ratio.

Several methods have been proposed and used for determining the colloid content of soils. None is entirely accurate and satisfactory, but the one used by Middleton seems to be considered among the best at the present time. It is based on the fact that colloids or "ultra clays," regardless of source, have nearly the same capacity to absorb water, *i.e.*, an average "specific water absorption" of 0.298. The colloid is measured by determining under certain conditions the water absorption of the entire specimen—which is the difference between the weight of the material when saturated and when dried at 110°C. and dividing the result by the constant 0.298.

The moisture equivalent is defined as the maximum percentage of moisture that a soil can retain in opposition to a centrifugal force equal to 1,000 times the force of gravity. Its determination is relatively simple in technique but requires special apparatus that is part of the standard equipment of every soils laboratory.

Middleton made a complete chemical analysis of the soils in Table 18 but was unable to discover any direct correlation between chemical characteristics and erosional behavior. On this point Middleton says,[1] "None of the chemical properties studied have been found useful in differentiating between erosive and non-erosive soils, though undoubtedly the dispersivity of a soil is influenced by the quantity and character of the exchange bases present (*pH* value), and the silica-sesquioxide ratio (molecular ratio of the silica to the combined alumina and iron oxide present in the colloid) is the determining influence on physical properties."

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[1] Middleton, H. E., "Properties of Soils Which Influence Soil Erosion," *U. S. Dept. Agr. Tech. Bull.* 178, 1930.

In a later publication in 1932, *U. S. Department of Agriculture Technical Bulletin* 316, the same author says:

> The dispersion ratio, and the erosion ratio are the only criteria that have been developed for estimating, in advance of actual measurement, the erosivity of a soil. . . . An analytical basis has been established, to which may be referred the future field behavior of these soils when it has been determined, so that a quantitative expression of anticipated behavior may (eventually) be developed.

In further explanation of the striking difference in erosivity of the soils in Group 2 of Table 18, J. F. Lutz remarks:[1]

> The aforementioned data show very clearly that one of the principal differences between erosive and non-erosive soils is the degree of aggregation of the finer mechanical separates into large, stable granules. . . . The Davidson aggregates are friable and porous; those in the Iredell are plastic and compact. The high content of large porous aggregates in the Davidson is in marked contrast to the small, compact granules and dispersed condition of the Iredell. The size of particles, whether primary or secondary units, determines to a great extent the amount of erosion by any given quantity of runoff.

143. Soil-fertility Surveys.—For a number of years the U. S. Bureau of Chemistry and Soils and various state agencies have been engaged in making field surveys and studies of the soils in the United States and classifying them according to productivity. Results are made available in the form of printed reports or bulletins by counties. These bulletins include soil survey maps and much valuable information about soils in the respective counties. Progress to date is indicated by the map shown in Fig. 70.

In commenting on this work the National Resources Board says:[2]

> Gradually methods have been modified as new conceptions of soil classification have developed and new needs for the data become

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[1] LUTZ, J. F., "The Physico-chemical Properties of Soils Affecting Erosion," *Univ. Mo. Research Bull.* 212, 1934.

[2] Report of the Land Planning Committee of the National Resources Board, December, 1934, p. 249.

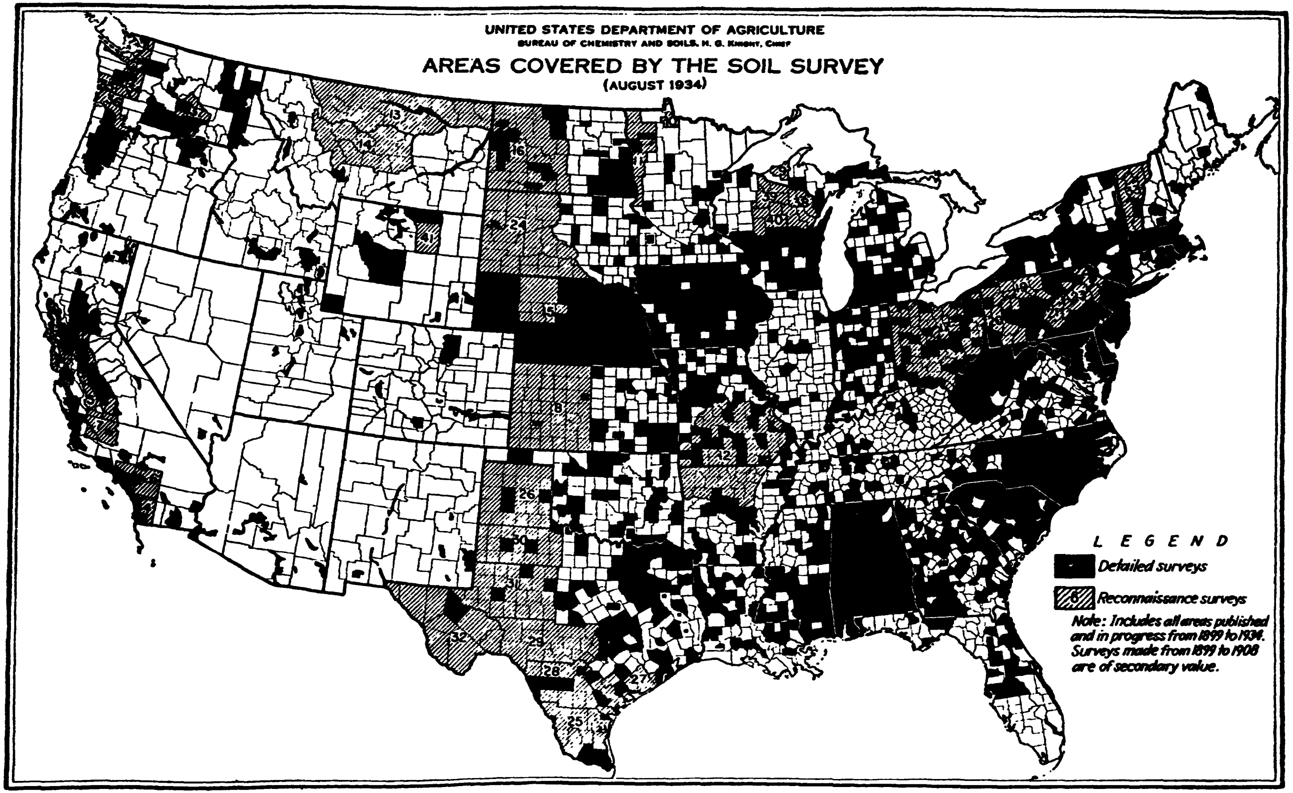
UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF CHEMISTRY AND SOILS, H. G. KNIGHT, CHIEF
AREAS COVERED BY THE SOIL SURVEY
(AUGUST 1934)
LEGEND
Detailed surveys
Reconnaissance surveys
Note: Includes all areas published and in progress from 1899 to 1934. Surveys made from 1899 to 1908 are of secondary value.

FIG. 70.—Map of the United States showing areas covered by the Soil Survey and available in printed form.

apparent. During the lifetime of the present soil survey in the United States the underlying philosophy has progressed from what may be termed the "geological" viewpoint to a basic concept that may be termed "climatological," The Survey now describes and appraises soils according to their important characteristics influencing productivity, including structure, depth and stoniness, texture, chemical composition, water-holding capacity, slope, and character of surface. As a result of recommendations by the National Land Use Planning Committee, the Survey undertook a classification and inventory of land types according to inherent physical productivity. This is in progress. These surveys are especially helpful for land use planning and, with such modifications and adaptations as may be found requisite to show relations to slope and surface conditions, should be rapidly extended.

CHAPTER XII

RAINFALL AND RUN-OFF

The required discharge capacity of all control channels or structures of whatever kind in soil and moisture conservation is predicated upon and determined by the source, rate of movement, and amount of surplus water to be removed.

144. Rainfall Characteristics.—The source of all run-off is, of course, precipitation, as either rain, sleet, or snow. Although it is known that evaporation and precipitation are equal, considering the entire earth's surface as a unit, meteorological laws governing the characteristics and distribution of precipitation are as yet but imperfectly understood. Nevertheless it is possible to gain much information of practical value from studies of precipitation records widely distributed in location and extending over long periods of time. While melting snow and ice are responsible for severe erosion and flooding in many localities, it is generally recognized that, in all but very special cases, works designed to carry run-off from critical rains will have sufficient capacity to handle the lesser volume from thaws. It is therefore common practice to direct precipitation studies largely toward a determination of rainfall characteristics.

In general, the records indicate that the following aspects of rainfall are approximately true.

Intense storms usually cover only small areas and are of short duration.

Storms lasting several days cover large areas and fall at low intensity.

The magnitude and intensity of any storm bears a direct relation to its average frequency of recurrence.

There does not appear to be any close relationship between the total annual rainfall at a given locality and the number or magnitude of intense storms likely to occur in a given time period.

The total or mean annual rainfall does give a good indication of the total volume of run-off, most of which occurs at less than critical rates.

145. Critical Run-off.—By "critical rate" of run-off is meant that rate which will produce the maximum volume per unit of time which is economically feasible to provide for in control channels.

While direct rainfall is the usual source of water available for and destructive to agricultural pursuits, it frequently happens that the most damage occurs at points more or less remote from the place where the rain actually falls. Water from upper levels becomes concentrated in flowing down slopes and finally spreads out over the lower lands adjacent to lakes, rivers, creeks, and small streams, rendering them unprofitable from an agricultural standpoint.

Wasteful use of irrigation water has also rendered untillable many areas of otherwise profitable soil, and still another source of damage to lowlands adjacent to sea or ocean is flooding due to tides or to windstorms that drive the water inland.

146. Annual Precipitation.—A special map of the United States, prepared by the U. S. Geological Survey and showing the amount and distribution of mean annual precipitation as determined from all reliable records to date, is represented in Fig. 71. The irregular lines superimposed on the map join points of equal annual precipitation in amounts as shown by the numerals in the lines, which represent yearly totals in inches. These numerals are average or mean values for the entire period of record, and the total for any single year may vary widely therefrom; in a period of 100 years a single year's record may vary as much as 50 per cent above or below the mean. The data are of value chiefly as differentiating humid, semiarid, and arid regions, and as indicators of the normal volume of run-off in any locality, most of which occurs at less than critical rates. There is nothing in these data to indicate how the total annual precipitation is distributed throughout the year by months or by seasons. Such data are available from publications of the U. S. Weather Bureau when needed for special studies.

The various state agricultural colleges, as well as numerous other public and private agencies, maintain weather observation stations where daily records are made and kept in permanent files.

147. Evaporation.—Evaporation of water, as hereafter considered, is taken in its broadest sense and is meant to include all the water which is evaporated, from the surface of the water, from the soil, or through the plant. The evaporation through the plant is usually spoken of as *transpiration*. In this discussion, however, it will be included under the head of Evaporation. The amount of evaporation that takes place is, of course, very hard to determine accurately; in fact, it is almost impossible to

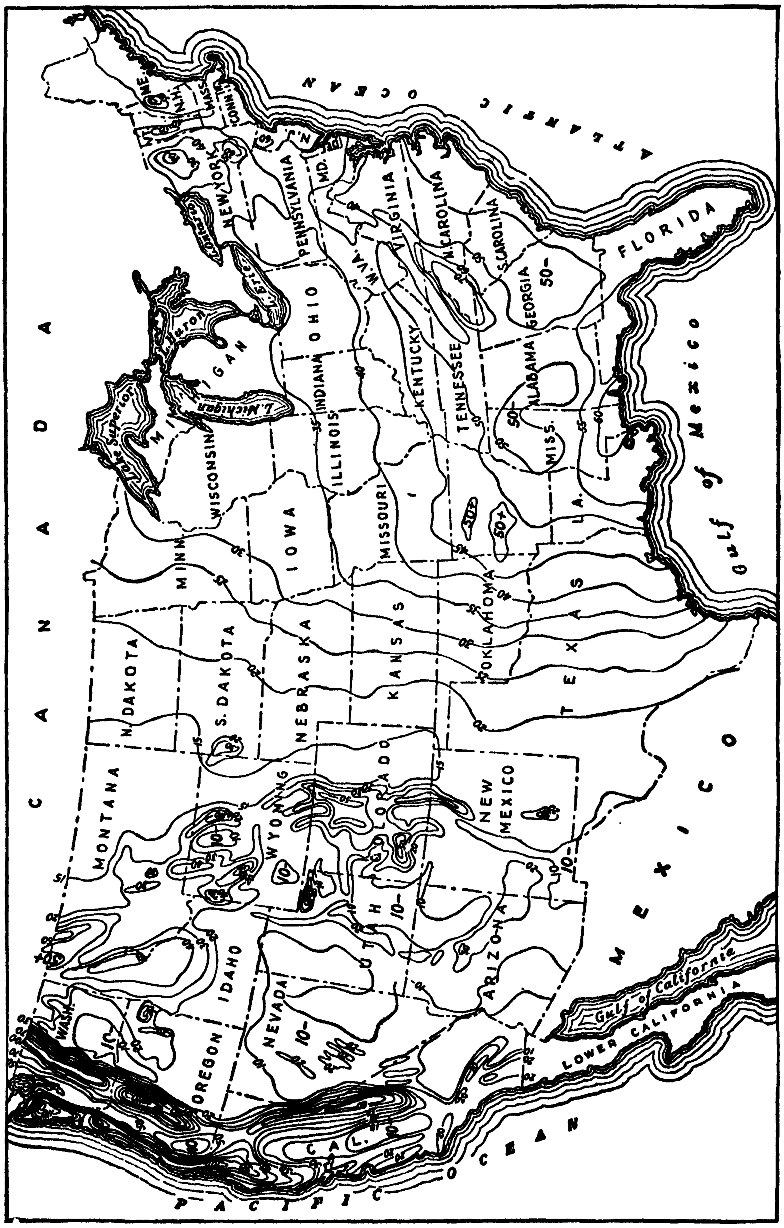

FIG. 71.—Map of United States, showing mean annual precipitation. Black lines and figures indicate average annual precipitation in depth in inches.

measure it. It varies with meteorological as well as physical conditions. Meteorological conditions that influence the rate of evaporation are temperature, vapor temperature, wind, and rainfall, while the physical conditions are topography, vegetation, and surface conditions of the soil.

148. Run-off.—The usual definition of *run-off* is the difference between rainfall and evaporation. This definition, while answering the purpose, is not very clear, in that it does not give any definite information with which to work. During and immediately after a hard rain, quantities of water will flow off the surface of the soil into the open channels. Other water will flow to lower levels through the soil and be removed by subsurface drains or by percolation through the soil to wells, streams, etc. This water which flows away, as a surplus, is called *run-off*.

Mead's definition of run-off is, perhaps, a clearer and a better one:

> The run-off is that portion of the rainfall that is not absorbed by the deep strata, utilized by vegetation or lost by evaporation and which finds its way into the streams as surface flow.

As in the case of evaporation, it is impossible to get an exact measurement of the amount of water that runs off. It is possible to get closer to it by actual measurement, however, than is the case with evaporation. Most of the run-off will go into the open channels, and, fortunately, water in open channels is easily measurable. It is this run-off in which we are particularly interested.

149. Factors Affecting Run-off.—It is evident that factors affecting run-off may be grouped into (1) rainfall characteristics and (2) watershed characteristics.

In erosion studies the rainfall characteristic producing the largest percentage and rate of run-off will invariably be storms of high intensity and short duration, because of the rolling or hilly nature and small size of the areas involved.

Watershed characteristics governing the amount and rate of run-off are: type, erosive condition, and physical nature of the soil; degree and length of slope; distribution and kind of vegetal cover; size and shape of drainage area; and upon whether or not channels exist to hasten the time required for water to concentrate at the point of exit.

The "time of concentration" is all-important because it determines the duration of the rain that will produce maximum run-off. It is measured by following the route taken by a given particle of water in traveling from the most remote part of the watershed to the point of exit and estimating the velocity of travel along various parts of the route. Maximum discharge occurs at the instant when water from all parts of the watershed first reaches the exit, and this means that the "critical rain" for any particular watershed is one which continues for a length of time equal to the time of concentration. Since the time of concentration varies with all the factors enumerated above, it will seldom be the same on any two watersheds, and hence the critical rain will vary to the same extent. It is a well-known meteorological fact that the more intense the rate of rainfall the shorter the time it lasts, so that, for a watershed of a given size and shape, the more the time of concentration can be prolonged the lower the rate of rainfall which must be dealt with.

NOTE: The terms "watershed," "drainage area," and "catchment area" are commonly used interchangeably.

150. Run-off Variable.—Run-off varies with rainfall, soil, topography, temperature, vegetation, shape and size of watershed, and natural storage basins.

The run-off will increase, all other things being equal, with the increase in intensity of rainfall and will increase with the amount of area affected by the storm. There will be less run-off when the rain occurs in light showers and when the area affected by the storm is small.

The kind of soil and the condition that it is in have a very direct bearing on the amount of run-off. A sandy soil will absorb more water before there is any run-off than will clay soil; while, in the case of rock or soil of a rocky nature, the ground will be more impervious, and the run-off will, of course, be greater. The condition of the soil has also much to do with the amount of run-off. If the soil is rough, there will not be so much run-off as if it were smooth. Farmers often take advantage of this fact by fall plowing and leave their fields more or less rough in order that the soil may absorb as much as possible of the winter rains. Fertile soils containing considerable humus have great absorbing capacity; hence, they do not allow the water to run off so rapidly or to the same extent as do poor soils. Again, if the ground is saturated from previous rains at the time a given storm begins, the run-off from such a storm will be much greater than it would have been if the soil had been dry.

The topography of the land has a great deal to do with the amount of run-off, because it determines to a large extent the length of time required for water to concentrate or pile up at a given point. In very hilly land having sharp slopes, the run-off is much greater than in flat lands.

The amount and the kind of vegetation existing over the area under consideration have a very direct bearing upon the run-off. Land having rank vegetation necessarily takes up and holds more water than land having little or none.

Large areas will have a smaller rate of run-off than small areas, because it takes the water longer to get to the ditch, and more of it soaks into the land.

The shape of the tract will also influence the run-off. A long, narrow tract with a ditch on the narrow side will have a smaller run-off than would the same tract with the ditch on the long side, for the reason that, in the former case, the water takes longer to get into the ditch, and thus more of it soaks into the soil.

The type of outlet into which this run-off goes from the various areas also influences the amount that runs off. If the outlets are good, the water gets away more quickly; if they are poor, the water moves more slowly.

Storage basins when so located that they absorb a considerable amount of water which would otherwise be discharged into open channels have a very direct bearing on the amount of run-off that must be taken care of by drainage channels. The main use of storage basins, however, is in flood prevention and irrigation.

151. Definition of Drainage.—The practice of drainage consists mainly in preventing surplus water from getting on or into the soil wherever possible and in removing from the surface and from the interior of the soil that surplus water which cannot be held off or intercepted.

152. Object of Drainage.—The object of drainage is to control the surplus water in such a way as to render the soil more suitable for cultivation and growth of crops; to provide more healthful surroundings; and to prevent erosion.

Land unfit for farming operations because of its surface being covered with water a part of the year is greatly benefited by drainage.

The removal of this water, by means of drainage, makes possible the growing of crops, which increases the value of the land from practically nothing, provided that the land is badly in need of draining, to an amount commensurate with the crop raised; or, if the land is only partly in need of draining, the increase will be commensurate with the increased yields.

The removal of this surplus water has an added advantage in that it removes the breeding places of various insects responsible for many of the ills of the human family. It also removes conditions conducive to lowering the vitality of the human body, thus rendering less susceptible to disease the people of a community in which swampy lands are drained.

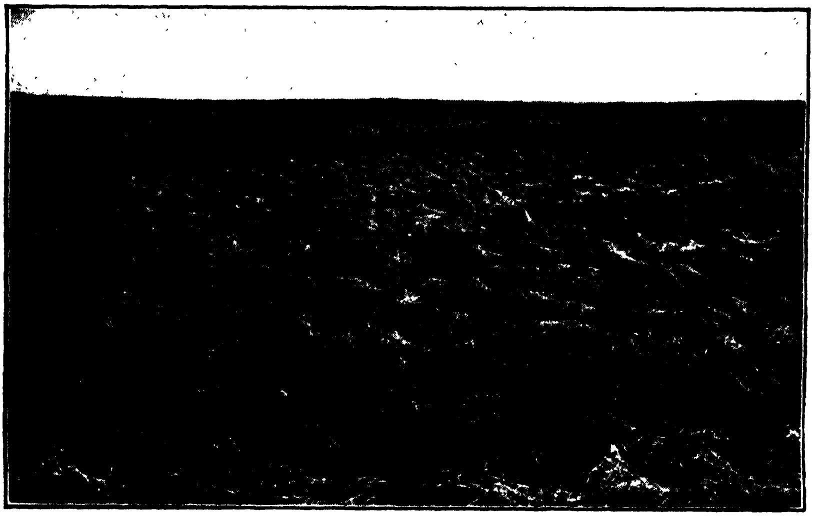

FIG. 72.—Typical wet land in need of subsurface drainage, Iowa.

Large amounts of uncontrolled water accumulating on hillside lands gain considerable velocity, cutting channels, destroying the uniformity of the surface of the land, and carrying away large amounts of the best part of the soil. The control of this water, by means of drainage, is clearly of great benefit.

There are many other benefits to be derived from the drainage of land, and they will be taken up in detail later.

153. Kinds of Drainage.—Drainage may be divided into two classes—surface and subsurface.

154. Surface Drainage.—Surface drainage consists of preventing surplus water from getting onto the surface of the soil as well as the removal of all surplus water directly applied. This is accomplished by various measures, such as levees, open ditches, plowing, subsoiling, and terracing.

155. Subsurface Drainage.—Subsurface drainage, more often called *tile drainage* or *underdrainage*, consists of the removal of the surplus water from the interior of the soil. This is accomplished by means of natural drainage (a gravelly subsoil) or by artificial drains placed under the surface.

156. Drainage Coefficient.—The amount of water that runs off from a given area in 24 hours is called the *drainage coefficient.* The unit of measure most commonly used for the drainage coefficient is depth in inches per 24 hours. Another unit is sometimes used—cubic feet per square mile per 24 hours. The first-named unit will be used in this text. The determination of this drainage coefficient, where the run-off for a given area is known as well as the number of acres in the watershed, is a very simple problem. The run-off of the area is found by gaging or measuring the stream which carries the water, the discharge of which is given in cubic feet per second. The total discharge of this stream is determined for 24 hours by multiplying the discharge per second by the number of seconds in the 24 hours. This amount of water divided by the number of square feet in the area discharging the water will give the drainage coefficient in feet per 24 hours, and by changing feet to inches, it is obtained in inches per 24 hours.

Example.—A ditch discharges 4.5 cubic feet of water per second and drains 640 acres. What is the drainage coefficient of this land?

$4.5 \times 60 \times 60 \times 24 = 388{,}800$ cubic feet in 24 hours, the discharge of the ditch.

There are 43,560 square feet in an acre.

$640 \times 43{,}560 = 27{,}788{,}400$ square feet.

$388{,}800 \div 27{,}878{,}400 = 0.014$ feet.

0.014 feet equals about $\frac{3}{16}$ inch.

The determination of the drainage area, if small, is not difficult, but the larger it grows the more difficult the process becomes. Often, the county map or a topographic map or even a map showing only the streams draining the area will serve to indicate the extent of the watershed and allow it to be computed.

157. Selecting Drainage Coefficient.—It is not often possible to determine with any degree of accuracy the drainage coefficient as outlined above; run-off for the area cannot be easily determined, because, during the storm periods, the present drainage channels are not sufficient, and the run-off spreads over considerable land, making measurement impossible. Hence, it becomes necessary to get all possible facts about this amount of run-off by measurement of streams and to these add such data regarding rainfall, character of land, and other factors (see above) as will assist in making an intelligent estimate regarding what drainage coefficient to use.

For small drainage areas, a small error in the drainage coefficient would make very little difference one way or the other. It would be best, of course, to have the error on the side of safety by making it too large rather than too small, as this would affect the size of the ditch very little and not materially increase the cost. In large projects, however, an error in the drainage coefficient of even a small amount would mean a financial loss to the district building the ditch. It is necessary, therefore, that a drainage engineer be employed on large projects in order that the drainage coefficient may be selected by one who has had considerable experience.

The determination of a drainage coefficient for a given area, to be drained by surface drainage, should take into consideration all the factors outlined under Rainfall, Evaporation, and Run-off. The problem must be studied from all these angles and with the assistance of such data as can be obtained from the various sources mentioned. The larger the project the more time and effort can be well expended on getting this information. For the average small drainage project, such as the farmer himself would attempt to solve, the coefficient would range from ¼ to 1 inch, depending upon its location and other factors.

158. Run-off Formula.—To design erosion structures with the proper capacity to meet the needs of their respective conditions it is necessary to make a quantitative determination of the critical run-off. This can be done by use of the following rational equation:

$$Q = CIA$$

where Q = critical rate of run-off in cubic feet per second.

C = run-off coefficient, (partially a coefficient of imperviousness) representing the ratio of the rate of run-off to the rate of rainfall.

I = rainfall intensity in cubic feet per second per acre, which unit happens to be approximately identical with the rate of rainfall in inches per hour.

A = watershed area in acres.

This equation was proposed by C. E. Ramser[1] as a result of measurements of rates of run-off and rainfall from small agricultural areas. The degree of accuracy with which critical run-off can be computed from the rational formula is, of course, no greater than that of the least accurate element, but even so it is far superior to empirical formulæ which are quite inflexible and make no adequate provision for the many variables involved.

In the present state of our knowledge the elements most difficult to evaluate are proper values for the coefficient C and the time of concentration which determines the rainfall rate to be selected for a particular locality. The watershed area can be taken from a map or measured in the field.

Ramser suggests control values for C as follows:[2]

TABLE 19.—VALUES OF C FOR USE IN FORMULA $Q = CIA$

Kind of watershed	Values of C
Cultivated, rolling, 5 to 10% slopes	0.60
Cultivated, hilly, 10 to 30% slopes	0.72
Pasture, rolling, 5 to 10% slopes	0.36
Pasture, hilly, 10 to 30% slopes	0.42
Timber, rolling, 5 to 10% slopes	0.18
Timber, hilly, 10 to 30% slopes	0.21

These values are a composite measure of all the variable factors affecting run-off. They should be considered as somewhere near the upper average limit and as applying to relatively impervious soils. To be on the safe side they are recommended for use unless a particular soil is definitely known to be exceptionally absorptive.

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[1] RAMSER, C. E., *Jour. of Agr. Research*, Vol. 34, No. 9, May 1, 1927.

[2] These figures are applicable only to small areas not exceeding 1,000 acres. For larger areas combined values of C would probably vary somewhat as follows:

Square Miles	Values of C
2 to 5	0.2 to 0.3
6 to 50	0.1 to 0.2
50 to 200	0.05 to 0.1

Accuracy of the time of concentration is dependent upon the accuracy with which the route of travel and velocity of flow can be judged.

This is not such a difficult task as it may at first appear, since the line of travel is usually in a more or less well-defined channel or channels wherein distance of travel is the chief variable as between watersheds subject to erosion. This being true, and if the shape is not abnormal, times of concentration become almost direct functions of watershed sizes. At least the values given in Table 20 may be used as a basis for estimates.

As will be noted, the figures given represent minimum times of concentration for channel grades approximating 5 feet fall per 100 feet. Since soil and cover variables, and to some extent prevailing watershed slopes, are taken care of in the values assigned to the run-off coefficient *C*, the interval representing the time of concentration is useful chiefly in selecting the proper rainfall rate for a particular set of conditions. Any increase that can be induced in the time of concentration will, of course, not only allow greater opportunity for absorption but will automatically reduce the rate of rainfall which results in critical run-off and hence will also reduce the rate of run-off.

TABLE 20.—TIME OF CONCENTRATION AS AFFECTED BY SIZE OF WATERSHED

Size of watershed, acres	Time of minimum concentration, minutes	Size of watershed, acres	Time of minimum concentration, minutes
1	1.4	300	29
3	3.0	400	35
5	3.5	500	41
10	4.0	600	47
20	4.8	700	53
30	8.0	800	60
50	12.0	900	67
100	17.0	1000	75
200	23.0		

159. Measurement of Run-off.—The water which flows in open channels is usually measured in the unit of cubic feet per second. This unit means that 1 cubic foot of water passes a certain point in the ditch every second.

There are three common methods used to measure the water in open channels—weir, current meter, and float.

The *weir* consists of a notched opening in the center of a dam placed across the channel to be measured. The water passes through this notch, and by the height of the water in the notch, the amount passing through can be determined by formulæ. These formulæ are the basis for tables which are available and which allow the results of the weir readings to be obtained very readily. It is essential that the water impounded at the weir should approach the weir at an average velocity not greater than ½ foot per second and that the crest of the weir notch should be sharp, level, and have its sides at the proper angle.

There are three common forms of weir notch—rectangular, trapezoidal (often called the *Cipolletti*), and triangular. The rectangular notch is used the most.

The *current meter* consists of a small wheel, made up of a number of buckets, which is free to revolve in a horizontal plane. This is attached to the base of a metal rod. The speed at which this wheel revolves indicates the velocity of the water in which it is immersed. These meters are very carefully rated at the factory where they are made, and their accuracy may be checked at any time at the rating station operated by the Bureau of Standards, Washington, D. C. There are two types of current meters—the electric current meter and the acoustic current meter. The former communicates to the operator through a telephone receiver, by means of an electric current, the number of times the current wheel revolves. The latter uses a tapping device the sound of which is conveyed to the ear of the operator through the handle of the current meter and a rubber tube. The electric meter is more generally used than the other type. When the length of time has been determined for any given number of revolutions of the wheel, this value is looked up in the rating chart of the current meter, which is usually found in the top of the box in which the current meter is kept. From this value can be determined the velocity of the water at the point where the current meter was held. The usual method of determining the discharge of the stream with a current meter is to select some accessible point on the stream from which to make soundings, getting the depth every 2, 5, or 10 feet across, depending upon the stream's size. These soundings can be made with a sounding line, or the current meter can be used. The average-velocity readings are then made by holding the current meter six-tenths the depth below the surface of the water. At this point, the velocity of the stream is supposed to be the same as the average velocity of that section of the stream. The discharge of the section is the product of the width, average depth, and the average of the velocity measurements taken at the ends of the sections. The total discharge of the stream is the sum of the discharges in the various sections.

The *float* method consists of determining the velocity of the surface of water in the open channel by means of a float. This float may be a chip or piece of wood of any kind. In using this method, it is necessary to select a section of the ditch which is straight and smooth. Place marks of some kind, such as poles or stakes, on the ditch bank, at some distance apart, say, 100 feet. Place the float on the stream above one of these marks and determine the length of time it takes it to travel the distance between the two marks. This should be repeated a number of times and the average taken, in order to get a result as correct as possible. The velocity should be converted into feet per second. The mean velocity of a stream varies from 0.8 to 0.95 of the surface velocity, the smaller percentage being used on shallow streams. Wind blowing up or down a stream will decrease or increase the surface velocity. The mean velocity times the average sectional area (in square feet) of the ditch, between the two points, will give the discharge. This method, at best, is more or less crude, and the results obtained from its use would not be very correct. It can be used, however, under such conditions as make it necessary.

Problems

39. A ditch discharges 20.01 cubic feet per second and drains an area of 46 square miles. What is the drainage coefficient?

40. A ditch discharges 14.21 cubic feet per second and drains an area of 3½ square miles. What is the drainage coefficient?

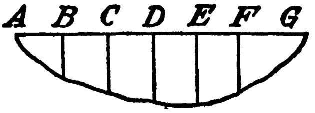
41. The drainage coefficient of an area of 5 square miles is ½ inch. What is the discharge of the ditch draining this area?

42. The drainage coefficient of an area of 13 square miles is ⅜ inch. What is the discharge of a ditch draining this area?

43. Six trials of the time in minutes required for a float to travel 150 feet on the surface of an open ditch were as follows: 1.5; 1.75; 2.00; 1.75; 2.25; 2.00. Soundings every 5 feet resulted in the following depths in feet: 3.25; 4.00; 2.50. The top width of the ditch was 20 feet. Compute the total discharge in cubic feet per second.

44. By use of a current meter the following mean velocities in feet per second were obtained in the cross-section of a ditch at the various points

shown: $A = 0.00$; $B = 2.46$; $C = 2.53$; $D = 3.01$; $E = 2.84$; $F = 2.60$; $G = 0.00$. Depth soundings in feet were as follows: $A = 0$; $B = 4.2$; $C = 5.4$; $D = 5.8$; $E = 4.9$; $F = 3.2$; $G = 0$. The distance between all the stations is 4 feet, except between F and G, which is 4.3 feet. What is the discharge of the ditch?



45. What is the coefficient of imperviousness of a tract containing "average" soil and having the following characteristics:

10 acres of rolling cultivated land.
15 acres of hilly pasture land.
5 acres of rolling timber.
5 acres of hilly timber.

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CHAPTER XIII

OPEN-DITCH DESIGN

Open ditches are in universal use, both as outlets for tile lines and for the direct removal of surface drainage. It is important, therefore, that the principles governing their design be understood. For this purpose it is necessary to consider some of the fundamental concepts regarding the theory of flow in open channels.

160. Velocity of Flow.—By *velocity* is meant the rate at which the water passes some given point in the ditch. It is usually measured in feet per second. The velocity of the water varies in different parts of the ditch. That next to the banks or bottom is slower than that in the other sections of the ditch due to the friction offered by the sides and bottom. The greatest velocity is just under the surface, at a point from 0.05 to 0.25 of the depth below the surface.

All velocity formulæ express velocity in terms of the mean velocity of flow; not necessarily the average of the velocities in all parts of the stream, but that velocity which when multiplied by the entire cross-sectional area will give the total discharge. In any vertical section the actual velocity at a point 0.6 of the depth below the surface is considered to approximate closely the mean velocity of the section. The mean velocity usually varies from 0.8 to 0.95 of the velocity at the surface.

There are a number of elements in the design of a ditch that influence the velocity of flow.

The depth of the ditch has a definite bearing upon the velocity of flow. It has been noted that the velocity of flow in the cross-section of the stream varies in its different parts and that the portion near the bottom of the ditch runs more slowly than the parts above it. The deeper the ditch, all other things being equal, the greater the velocity.

Velocity of flow varies inversely as the square root of the wetted perimeter. The wetted perimeter is that portion of the cross-section of the ditch that comes in contact with the water or, in other words, the length of the two sides and the bottom, usually expressed in feet.

Velocity of flow varies with the grade of the ditch. By the *grade* of the ditch is meant the amount of fall it has in a given distance. It is usually expressed in feet or tenths of feet, per 100 feet or mile. In some cases, the grade is given in the form of a slope—the slope being the fall, in feet, divided by the length, in feet, of the section considered. The slope is invariably expressed as a decimal fraction and represents the fall in feet per foot.

161. Velocity Formulæ.—There are a number of formulæ which are being used for determining the velocity of water in open channels. Space does not permit a discussion here of all of them. It may be said, however, that most of the large drainage ditches are designed by the use of the Chezy-Kutter formula; but this is a very tedious one to use, unless a set of special tables is at hand to assist in its solution. There is a simpler one, known as *Elliott's open-ditch formula,* which gives sufficiently accurate results for the small ditches such as the student, using this text, will be called upon to design.

FIG. 73—Typical open ditch draining cut-over land. This ditch has a fall of 6 feet per mile and is 20 feet wide and 7 feet deep. The timber and brush shown on the right has been cleared since this photograph was taken.

162. Elliott's Open-ditch Formula.

$$V = \sqrt{\frac{a}{p} \times \frac{3}{2}h}$$

Where V = mean velocity in feet per second.
a = area of cross-section of ditch in square feet.
p = wetted perimeter in feet.
h = fall in feet per mile.

163. Discharge of Ditches.—In order to obtain the discharge of a ditch, it is necessary to know the mean velocity of flow as obtained above, which then, multiplied by the area of the cross-section of the ditch in feet, will give the discharge in cubic feet per second; or, expressed as a formula:

$$Q = av.$$

Where Q = discharge in cubic feet per second.
a = area of cross-section of ditch in square feet.
v = mean velocity of flow in feet per second.

164. Number of Acres Ditch Will Drain.—With the discharge of the ditch known, the number of acres drained can be obtained by dividing the ditch discharge by the amount of water that is to be removed from each acre, or, expressed in a formula, as follows:

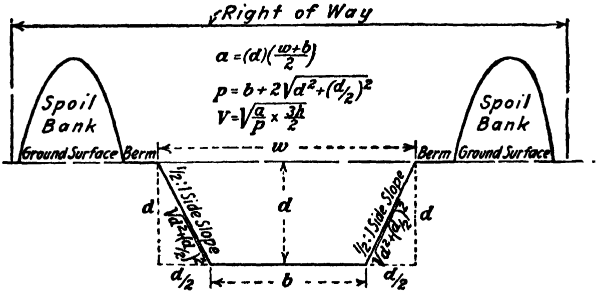

FIG. 73A.—Sketch showing elements of an open ditch cross-section.

$$A = \frac{Q}{Z}.$$

Where A = number of acres.
Q = discharge in cubic feet per second.
Z = amount of water to be removed from each acre in cubic feet per second.

It will be noted that Z is the same as the drainage coefficient, spoken of in Art. 156, except that its unit in this case is *cubic feet of water removed per second per acre*, while, in the other case, it was *inches in depth per 24 hours*. The conversion of the drainage coefficient to Z is a simple problem.

For example, what would be the value of Z, if the drainage coefficient was ½ inch for an area of 1 acre?

½ inch equals 0.04166 feet.

1 acre equals 43,560 square feet.

Water ½ inch deep over 1 acre equals 0.04166 times 43,560, or 1,814.709 cubic feet of water to be removed each 24 hours. There are 60 minutes to an hour, 60 seconds to a minute; so, in 24 hours, there would be 3,600 times 24, or 86,400 seconds. The amount of water that must be removed each second will be equal to 1,814.709 divided by 86,400, which is 0.0210, the value of *Z* for a drainage coefficient of ½ inch.

Table 21 has been computed in order to give the values of *Z* for the different drainage coefficients.

TABLE 21.—VALUES OF *Z* FOR VARIOUS DRAINAGE COEFFICIENTS

Drainage Coefficient, Inches per 24 Hours	*Z*, Cubic Feet per Second per Acre
1	0.0420
15/16	0.0394
7/8	0.0367
13/16	0.0341
3/4	0.0315
11/16	0.0289
5/8	0.0262
9/16	0.0236
1/2	0.0210
7/16	0.0184
3/8	0.0157
5/16	0.0131
1/4	0.0105
3/16	0.0079
1/8	0.0052
1/16	0.0026

165. Side Slopes.—The side slopes of a ditch are the slopes that its sides make with the horizontal. It is necessary to give the sides of an earthen ditch some slope other than the true vertical. If the sides were absolutely vertical, in the average soil, they would not remain in that condition long but would slough off and finally take such an angle of repose that the soil would remain firm. Side slopes of banks are usually given in the number of feet, or parts of a foot, that the bank goes in a horizontal direction to 1 foot vertical.

For example, a slope of ½:1 means that for every 6 inches the bank goes horizontally it will rise 1 foot vertically. This slope would be a steep one, while a slope of 3:1 would be a flat slope.

In selecting the slope for a ditch, it will be necessary to consider the kind of material through which the ditch is to be dug. A rock formation could use vertical sides; a loose rock or hardpan soil, ½:1; a clay soil, 1:1; a sandy loam, 2:1; a very sandy soil, 3:1.

166. Selecting Velocity for Open Ditches.—The grade that can be given a ditch is more or less limited by the fall of the land through which it is located. This grade, however, can be modified by shortening or lengthening the ditch, or by digging it deeper, but to lower the grade by digging a longer ditch is an expensive method and should be used only in extreme cases. The velocity can better be lowered by the design of the ditch itself. The influence of the various factors in ditch design on the velocity has already been discussed. The ideal ditch is one so designed as to obtain a velocity sufficient to make the ditch self-cleaning yet not enough to cause it to cut more deeply or erode the sides. In order to get this desirable velocity, it is necessary to design the ditch for the soil through which it is built.

Etcheverry[1] gives the following as the safe maximum values of mean velocities safe against erosion:

Material	Mean Velocity in Feet per Second
Very light, pure sand of quicksand character	0.75 to 1.00
Very light, loose sand	1.00 to 1.50
Coarse sand or light sandy soil	1.50 to 2.00
Average sandy soil	2.00 to 2.50
Sandy loam	2.50 to 2.75
Average loam, alluvial soil, volcanic-ash soil	2.75 to 3.00
Firm loam, clay loam	3.00 to 3.75
Stiff clay soil, ordinary gravel soil	4.00 to 5.00
Coarse gravel, cobbles, shingles	5.00 to 6.00
Conglomerates, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	6.00 to 8.00
Hard rock	10.00 to 15.00
Concrete	15.00 to 20.00

The experience of United States engineers indicates that an average velocity of from 2 to 3 feet per second will prevent the deposit of silt.

More exactly, the velocity needed to prevent silting or erosion varies with the depth of flow according to the following relationship (for fine sandy silt):

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[1] "Irrigation Practice and Engineering," Vol. 2.

Depth, Feet	Feet per Second
1	0.84
2	1.30
3	1.70
4	2.04
5	2.35
6	2.64
7	2.92
8	3.18
9	3.43
10	3.66

167. Desirable Cross-section of Ditch.—In designing an open ditch, cheapness and efficiency should be the objects. A ditch which is twice as wide as it is deep will be the cheapest, as far as cost of excavation goes. A desirable depth for the ditch is from 6 to 12 feet. A bottom width less than 4 feet is difficult to construct and clean out, except by hand.

168. Determining Drainage Capacity of an Open Ditch.—In order to show the method followed in determining the capacity of an open ditch, the following example with its solution is given:

How many acres would a ditch drain which is 8 feet deep; has a bottom width of 6 feet; side slopes, 1:1; grade, 1 foot per mile; drainage coefficient, ½ incL? Using Elliott's formula for open ditches:

$$V = \sqrt{\frac{a}{p} \times \frac{3}{2}h}$$

To find p, it is necessary to find the length of the sides which the water touches. Each side, if the ditch is running full, is the hypotenuse of a right-angled triangle of which the sides are 8 feet long. The hypotenuse is equal to the square root of the sum of the squares of these two sides. Therefore, the length of one of the sides of the ditch is 11.3 feet. Then p equals 11.3 plus 11.3 plus 6 or 28.6 feet.

To find a (area of cross-section of ditch), the mean width of the ditch, which is 6 feet at the bottom and 22 feet at the top, will be 14 feet; this 14 feet times the depth of 8 feet, equals a, which, in this case, is 112 square feet; h, the fall in feet per mile, equals 1 foot.

$$V = \sqrt{\frac{112}{28.6} \times \frac{3}{2} \times 1} = 2.42 \text{ feet per second}$$

Velocity = 2.42 feet per second.

The discharge of the ditch would be $Q = av$.

$Q = 2.42 \times 112 = 271.04$ cubic feet per second.

The number of acres this ditch will drain with a drainage coefficient of ½ inch is.

$$A = \frac{Q}{Z}$$

$$A = \frac{271.04}{0.021} \text{ acres.}$$

$$A = 12{,}906 \text{ acres}$$

169. Determining the Size of Ditch for a Given Area.—The problem in ditch design is usually presented in this way: to design a ditch to drain a certain piece of land. The fall, or grade, of the ditch being given, the type of soil through which it flows will limit the side slope and the velocity, while the drainage coefficient is assumed.

The method of attack for such problems is to assume a ditch of certain proportions which it is thought will drain the area with the drainage coefficient taken. With the assumed dimensions of the ditch and other factors given, properly substitute in the above formula and determine the capacity of such a ditch. If it will drain the required number of acres in the watershed, then the assumption is correct, and it is the ditch to build. If it is too large or too small to drain the required area properly, then the dimensions should be changed and the ditch refigured, continuing thus until the desired ditch is obtained.

Fig. 74.—A channel with a good fall and erosive soil will increase in size when straightened.

In working out such a problem, it is well to remember that it is not practicable to get a ditch which will drain the land in question to the exact acre, but it should drain within a few acres and that, if possible, should be an excess.

170. Depth of Water in Ditches.—In designing ditches, it is well to design them so that they will flow 0.8 full. The best method is to compute the ditch flowing full and then deepen it so that the water will be only 0.8 of the final depth.

If a ditch is not made so large as is desirable, it should have the required depth in preference to the width, for usually a ditch will increase its capacity by eroding the sides rather than by washing out the bottom.

Problems

46. A piece of land has a clay soil and a fall of 1 foot per mile. If a ditch is dug 5 feet deep, with a bottom width of 4 feet, from how many acres of land will it remove ½ inch of water in 24 hours?

47. The velocity of a ditch is 3.5 feet per second; its cross-sectional area is 5 square feet. From how many acres will it remove ¾ inch of water per 24 hours?

48. A piece of land 2 miles square must be drained by a ditch which has a fall of 1½ foot per mile; 1 inch per 24 hours is to be removed. The soil is sandy. Design the ditch.

49. What is (*a*) the velocity of a ditch having bottom width of 6 feet; side slopes of 2:1; fall of 1 foot per mile; and depth of 3 feet? (*b*) the velocity with a depth of 6 feet?

50. What is (*a*) the velocity of a ditch having a bottom width of 4 feet; side slopes 1½:1; fall of 1.25 feet per mile; and depth of 8 feet? (*b*) the velocity if the ditch has a bottom width of 8 feet?

51. What would be the velocity of the ditch in (*a*) of Prob. 49 if the fall of the ditch were 2 feet per mile?

52. How many acres would the ditch in (*a*) of Prob. 50 drain with (*a*) a drainage coefficient of ½ inch? (*b*) a drainage coefficient of ¾ inch?

53. How many acres would the ditch in (*a*) of Prob. 49 drain with (*a*) a drainage coefficient of ⅝ inch? (*b*) a drainage coefficient of ⅞ inch?

54. Design a ditch to drain 25,000 acres of sandy loam land. The fall is 1 foot per mile and the drainage coefficient is ⅛ inch.

55. Design a ditch to handle the land in problem 54 when a drainage coefficient of 3/16 inch is used.

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CHAPTER XIV

OPEN-DITCH LOCATION AND CONSTRUCTION

Where a ditch is to be put in for the benefit of a farm or two of small acreage, it is possible for the farmer who has had training in drainage to do this work. But should the ditch drain a large area, *i.e.*, take in many farms or even one large farm of thousands of acres, it is far better to employ a competent drainage engineer. This engineer can save considerable money because of the experience and knowledge which enable him to locate and determine the size of the ditch better than could those not having this training or experience. He will usually save many times his fee.

171. Drainage Engineer.—In selecting a drainage engineer to do this work, his ability, honesty, and experience should be carefully considered. The drainage projects on which he has worked should be looked into, and the opinion of the authorities in charge of these projects secured. His standing among other members of his profession should, if possible, be determined. A good man is always honored by the majority of his coworkers. It is considered a valuable asset to all engineers to have received a college education. As a rule, those having this training, together with some experience, are the better engineers. There are, however, capable drainage engineers who have not had the advantage of college training but who have learned drainage design by practical experience; the necessary technical knowledge, which they must have, has been dug out at the cost of midnight hours. Most engineers are honest, and as a class they rank high in this regard, but, in spite of this, there are among them some who are unscrupulous. As a rule, the latter are soon eliminated from the profession, as reputations travel rapidly.

The method of making surveys for open ditches is much the same as for a railroad or new highway. It consists of making three distinct surveys—reconnaissance, preliminary, and location.

172. Reconnaissance Survey.—The first thing to be done in a survey for open ditches is to go over the ground on foot or horse-

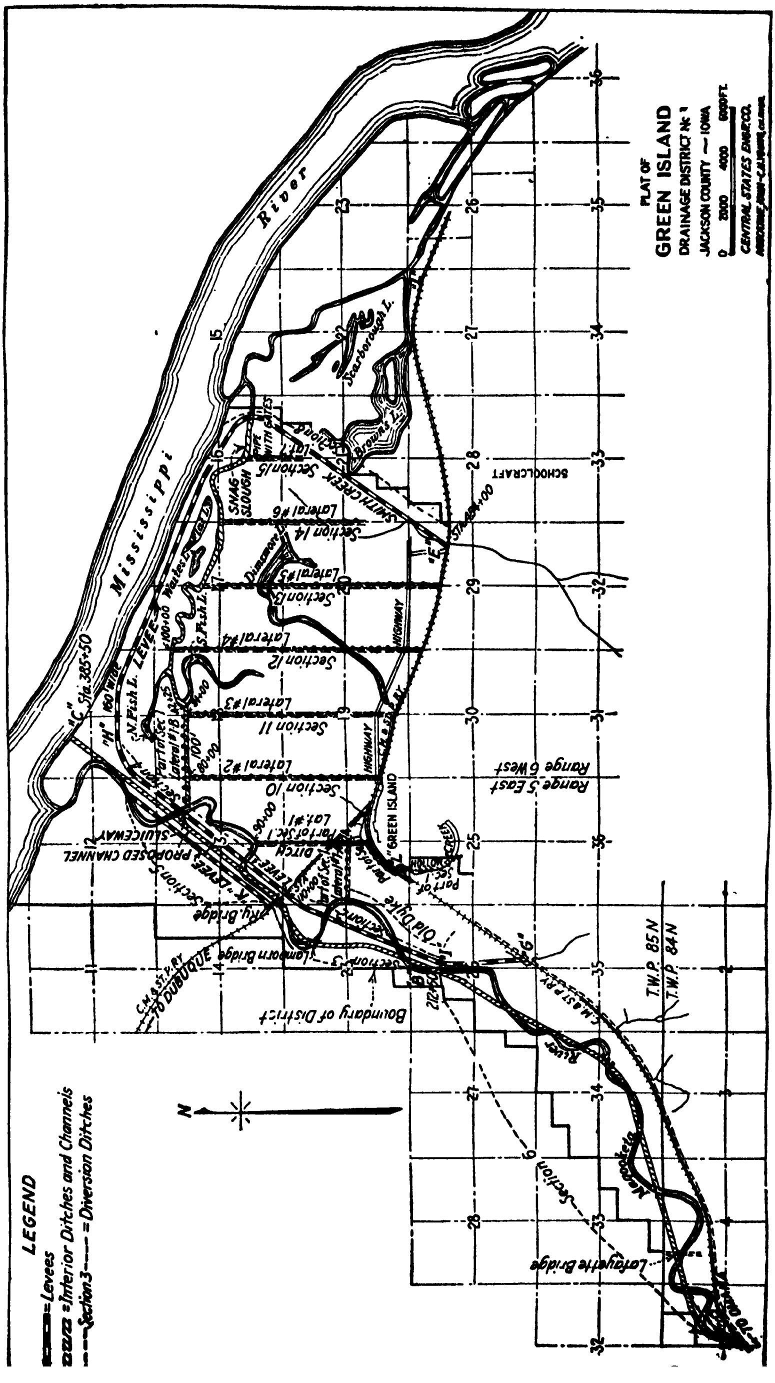

FIG. 75.—Typical drainage district in the Upper Mississippi Valley combining the use of channel straightening, stream enlargement, levees, interior ditches, and diversion ditches.

back and get, from such inspection, as good ideas as possible of the drainage problem. To be noted are:

Topography of the watershed area.
Size and extent of the drainage area.
Possible location of the drainage outlet.
General character of soil throughout drainage area.
Amount of cultivated and uncultivated lands.
Kind and grade of crops.
Number, extent, and size of natural waterways.
Kind of survey that it will be necessary to make.

In addition to all this, the engineer should collect every county, private, state, and government map which will give him any data to assist in the solution of the problem at hand.

The care with which the reconnaissance survey is made will have considerable influence on the other surveys and will determine the amount of time and money that can be expended for any and all of them. It is important that the engineer, after the reconnaissance, have a very clear picture in his mind of the size and extent of the drainage problem.

173. Preliminary Survey.—After the reconnaissance survey, the drainage engineer should proceed to obtain the facts enumerated above in a way as accurate as time and conditions will permit. This step is called the *preliminary survey.* The size and character of the entire project will determine the kind of preliminary survey; the necessary survey for a small area, for instance, would be different than for a large one, while that called for where the land was in a narrow valley would not be the same as for a flat swamp. The surveys should comply with the state laws, however—whatever they are.

The preliminary survey will result in a map of the drainage area which will show some topography, the location of the ditch or ditches, and sufficient information to design the ditch. The various things on which information is to be accumulated may be itemized as follows:

Area and shape of watershed.
Rainfall data for area.
Topographical map of sufficient area to locate ditches.
Type and condition of subsoil.
Ownership of land.
Amount of cultivated and uncultivated land.
Location and gaging of natural waterways.
Natural storage basins.

174. Locating Survey.—With the center line of the ditch plotted on the map, the next thing is to locate it on the ground. This is done by starting at the lower end and measuring the length of the ditch on the ground, along the line shown on the map. When the ditch changes its course, the angle is determined by the angle of the ditch on the map, this same angle being laid off on the ground. Stakes are set up every 100 feet along the line of ditch, these being marked 0 + 00 at the outlet and numbered consecutively up the ditch.

When the ditch is finally located on the ground, a line of profile levels is run over it, and these levels plotted on profile paper showing the surface of the ground along the line of the ditch. Upon this profile, the grade line of the ditch is also plotted. This is done just below the ground line and at the same depth at which the ditch is to be constructed. When the grade line of the ditch is finally plotted, the difference between it and the ground line at each of the 100-foot stations will be the cut—or the amount of excavation for the ditch at each of these points. These cuts should be obtained for each station and marked on the grade stakes at the center line of the ditch.

175. Location of Open Ditches.—There is no fixed rule or set of rules that will enable one to locate every ditch, as each location presents an individual problem which must be solved by taking into consideration the conditions involved. This calls for original study and the use not only of the principles of surface drainage, as laid down, but also of a great deal of common sense. Parsons gives the following general points to be kept in mind in the location of open ditches:

1. The value to stream flow of straight courses and gradual curves.
2. The desirability of locating drains along property lines wherever possible.
3. The damage to farms of ditches so located as to cut off small inaccessible corners, or extending across them in angling or irregular directions.
4. The economy of traversing natural depressions.
5. The injurious effect of unstable soils upon ditch construction and maintenance.

176. Curves for Open Ditches.—Where it is necessary to change the direction of a ditch, this should be done by means of easy curves rather than right or acute angles, because water will not change its course abruptly. If an attempt is made to make it do so, erosion of the banks will be the result.

When the angle the ditch makes is very large, approaching 180°, it is not difficult to put the curve in by eye. The same is true of all small ditches, no matter what the degree of the angle. When a large ditch on a flat piece of land has a 90° curve (or thereabouts), the curve can best be run in with an instrument, and the same method used as for railroad work. This method is too complicated to take up in detail here. The topography of the land will often determine the curve to be used in the ditch.

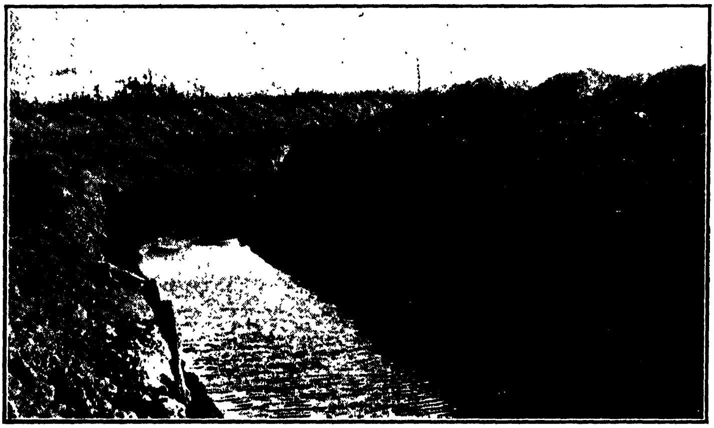

FIG. 76.—A typical dredged ditch at a curve showing side slopes, berms, and spoil banks.

177. Construction Methods.—The digging of open ditches may be done in six different ways—by hand, scrapers, drags, road graders, dredges, and dynamite. Each one of these methods has its proper place and, therefore, its mission in open-ditch construction.

178. Digging Ditches by Hand.—The excavation of ditches by use of the pick and shovel is the most expensive of all methods and should be used only where other methods are not possible. In constructing small ditches or in cleaning out old ditches where scrapers or drags cannot be worked to advantage, because of too much moisture and the presence of stumps or rocks, handwork must be resorted to. This method of ditching varies greatly in cost, because of the different types of material handled, obstacles met, and price of labor. If the soil is dry and hard, or wet and sloppy, it will cost more than it would if it were just damp and easy to work with.

179. Digging Ditches with Scrapers.—There are more small ditches, on farms, dug by means of scrapers than by any other means due to the fact that the equipment is not costly and is usually found on the farm. There are three types of scrapers used for this purpose—slip, wheel, and Fresno.

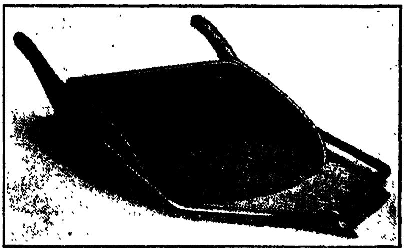

Fig. 77.—Slip or drag scraper.

The slip or scoop scraper (Fig. 77) is of small capacity, usually holding from 3 to 7 cubic feet. These scrapers are well adapted to small jobs where the dirt is not to be hauled any distance but emptied near at hand. The cost of moving dirt with this scraper varies, depending on the size and depth of the ditch.

The Fresno scraper (Fig. 78) is a wide, shallow scraper with two runners extending in front of it and a long handle in the back. This scraper slides over the ground in the same manner as the slip scraper. It comes in varying widths from 3½ to 5 feet and capacities from 8 to 12 cubic feet. The advantages of this scraper over the slip scraper are that it can be filled and emptied by the driver with greater ease than the slip, and the dirt, as it is emptied, can be distributed uniformly over a given area. The cost of moving dirt with this type of scraper is, perhaps, a little less than with the slip scraper.

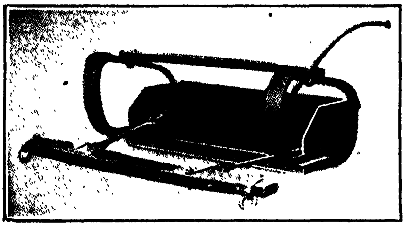

Fig. 78.—Fresno scraper.

The wheel scraper (Fig. 79) consists of a large slip scraper, mounted on wheels, to which a tongue is attached. This scraper is provided with levers for raising and lowering the scoop to load and empty it. It has a capacity of from 9 to 16 cubic feet. Where the dirt is to be moved over 100 feet and the soil is dry, it is desirable to use this type of scraper, as it is more economical in long hauls. Should the soil to be moved be stony and full of roots, the slip scraper is best, as it moves over the ground better. In ditching, the hauls are hardly ever long, except in such cases as building levees or dams across streams. The cost of moving earth with this type of scraper varies with the distance the earth is to be hauled.

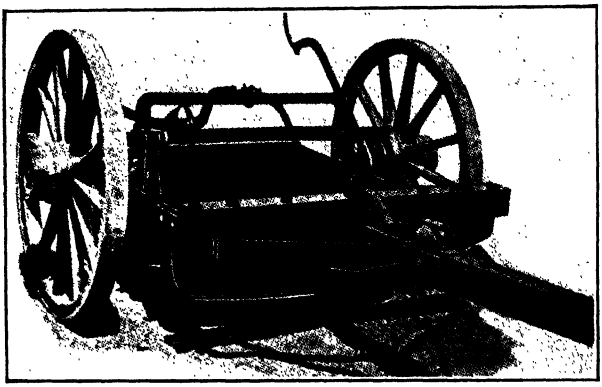

FIG. 79.—Wheeled scraper.

180. Drags as Ditchers.—The V drag (so-called because it is built in the shape of a V) can be built of wood at home or purchased in steel, is an excellent earth mover for small surface ditches, but is not to be recommended for deep or large ditches (Fig. 80).

FIG. 80.—Digging ditches with the V-drag. (*Univ. Minn. Agr. Exp. Station, Bull.* 217.)

181. Road Graders and Ditchers.—The road grader is often used with good success as a ditching machine. As a general rule, it should never be purchased for this purpose alone, as it is not made especially for ditching and is expensive. Where it is already owned or can be borrowed to use in constructing small or shallow surface ditches, it may be good policy to use it. It is built in a large number of sizes, from the one handled by two horses on up. The smaller sizes can be handled more profitably by the average farmer because of the amount of power required. It, of course, requires a firm footing to work on; hence, it would not be of any use in places where the ground was very soft.

FIG. 81.—Elevating graders building ditches. (*Courtesy of Western Wheeled Scraper Company.*)

182. Elevating Graders as Ditchers.—The elevating grader consists of a large plow which throws the earth from the moldboard onto an endless apron, which elevates it to a certain point at one side of the machine. Usually dump wagons are placed under this elevator, and the earth carried away; but for ditching, the elevator throws the earth onto the bank. This is a very cheap way to excavate where the ground is dry and will allow the machine to operate without miring up (Fig. 81). The above-named condition is seldom found where drainage ditches are needed; hence, this machine is seldom used for such work but is better adapted for construction of irrigation ditches.

183. Dredges.—Strictly speaking, a dredge is a power excavator equipped with floating supports. If the same machinery were mounted on "caterpillars," rollers, or some other form of land support, it would be called a *land excavator*. It serves the purpose of this book, however, to call all such machines *dredges*, which implies that the actual digging is done underwater.

From a practical standpoint, it is desirable that the engineer know in advance what kind of machinery is likely to be used in construction and the limitations of such machinery, so that he may design the ditches to suit. For instance, if a floating dredge is to be used, the ditches must all be so interconnected, that the dredge may float from one to the other.

FIG. 82.—A typical right-of-way of a drainage ditch ready for the dredge.

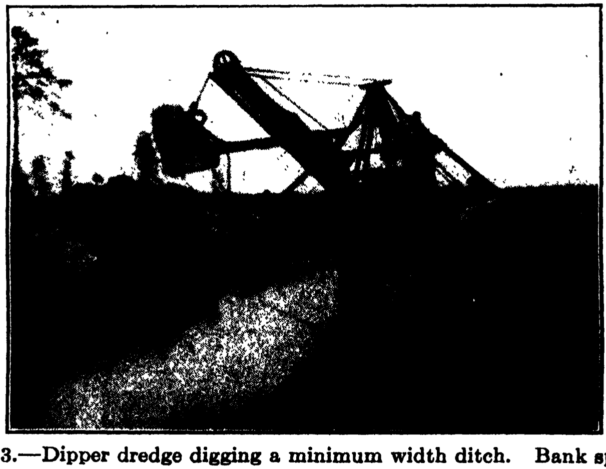

FIG. 83.—Dipper dredge digging a minimum width ditch. Bank spuds.

There are many kinds of dredges used for digging ditches. The principal ones can be divided into three groups—floating-dipper dredges, land dredges, and hydraulic or suction dredges.

The *floating-dipper dredge* (Fig. 83) consists of a boat on which are mounted an engine and boiler together with necessary machinery for operating a dipper to do the digging. This dredge is a steam shovel placed on a boat. In its smaller types, it is used for digging ditches for drainage and irrigation purposes.

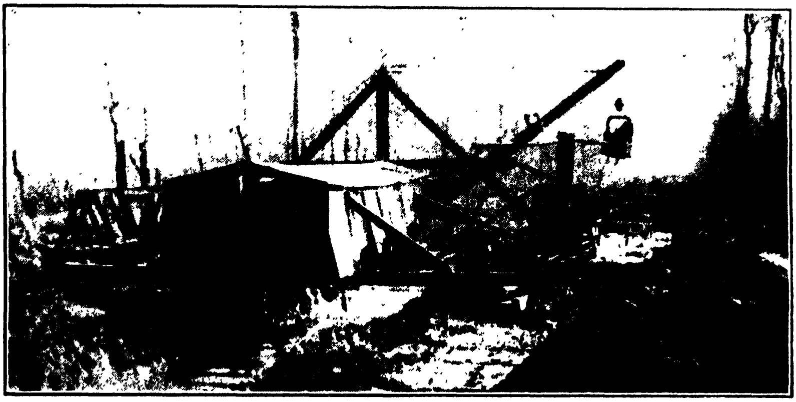

FIG. 84.—Walking dredge operating in Mississippi.

The dredge always works downstream whenever possible, as in this way it is assured of sufficient water to float it without building dams across the ditch. In the past, this machine has been used more than any other type for ditching, in spite of the fact that it cannot do smooth work. Another objection is the fact that, as the dredge works downstream, quantities of soft mud, which do not always wash out later, are likely to accumulate behind it.

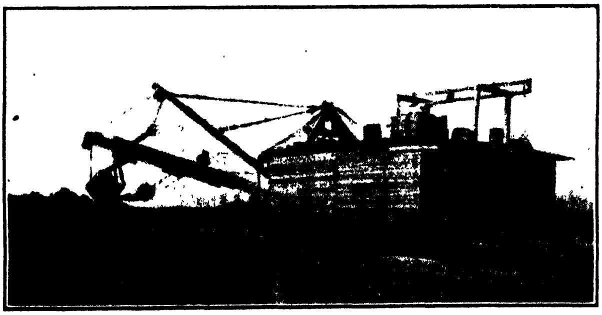

FIG. 85.—Type of walking dredge used in developing cut-over land in Minnesota.

These types of dredges cost from $500 to $25,000 depending upon the size of buckets which they will handle.

The *land dredges* are of various forms (Fig. 84) and shapes and use the same type of dippers as the floating dredges. Their distinguishing feature, however, is that they are operated not by floating on water but by being hauled or dragging themselves

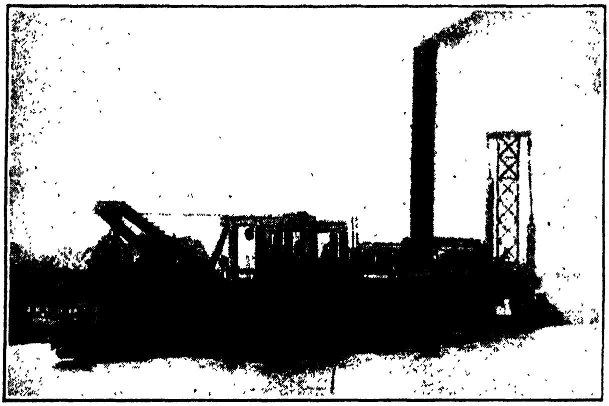

Fig. 86.—Hydraulic dredge showing suction cutter head which revolves at high speed and is connected to the suction end of a centrifugal pump.

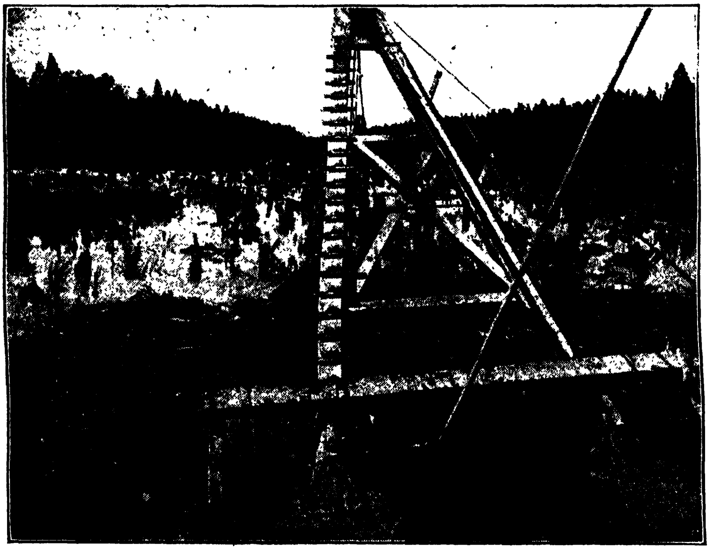

Fig. 87.—Looking forward from the hydraulic dredge "Texas" in the New Orleans Industrial Canal showing character of material handled.

along the sides or on the bottom of the ditch. They may move along on a rail or use four large pods and walk (Fig. 85). They are equipped with an engine, boiler, and necessary machinery for using a dipper. These types of dredges are used where water is not available to float a dredge or for small ditches. They are built in ½- to 1-yard bucket capacities.

The *hydraulic dredge* consists of a boat equipped wth engines and pumps (Fig. 86). The material to be moved must be soft (unless a special cutter-head is used) and contain considerable water. It is sucked up through a large pipe by means of a pump and discharged through a pipe at some distance. This dredge is used more often for cleaning out channels than for digging ditches, as the material should be soft and easily moved (Fig. 87). These dredges cost from a few thousand up to a hundred thousand dollars.

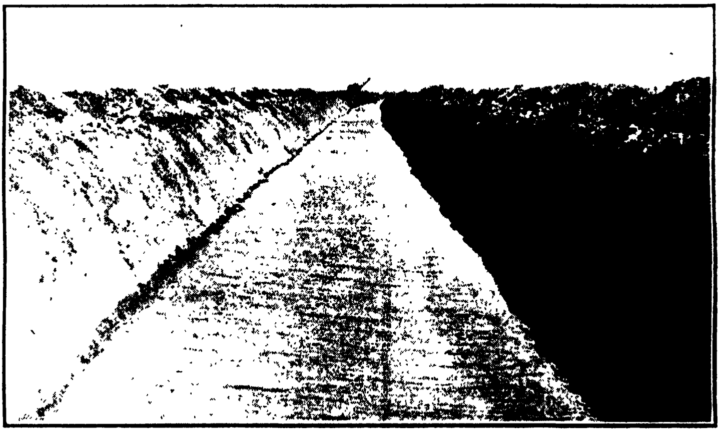

FIG. 88.—An open ditch dug by a drag-line excavator.

184. Dragline Excavator.—The dragline excavator (Fig. 89) does similar work to the dredges but differs from them in that it is always working above the excavation, and it is always on dry land—either on the land to be excavated or to one side of it. The machine has machinery similar to a steam shovel but is mounted on some sort of track such as a "caterpillar," or track-laying mechanism, which allows it to propel itself. It is a comparatively new machine but has become very popular. It works in difficult soils with success and is made in sizes ranging from ½ to 3½ yards.

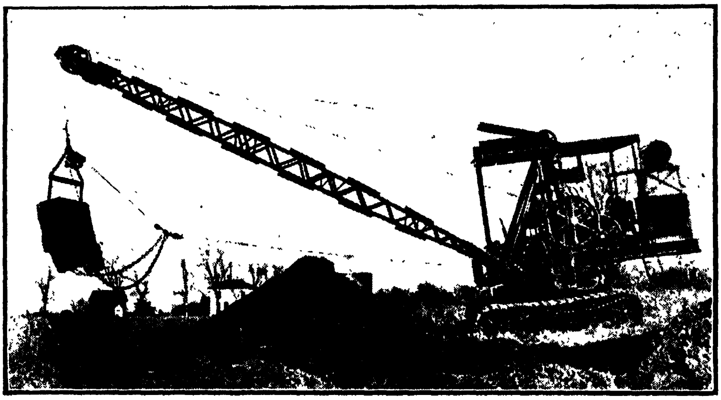

FIG. 89.—A typical drag-line excavator, ½-yard bucket, 30-foot boom. (*Courtesy of Parsons Company.*)

185. Dippers and Buckets.—There are several kinds of buckets that are often used for the same purpose as the dipper, namely, clamshell, orange peel, and dragline.

The dippers used by these dredges are of rectangular shape, having an open top and a hinged bottom. They are loaded by scooping the earth in the top and unloaded by tripping a latch on the bottom, allowing it to fly open. The lip of the dipper which does the scraping is provided with a number of heavy teeth to prevent rapid wear on the bucket itself. These teeth are generally removable, so that they can be easily replaced or taken off and sharpened. By reason of its "rough-and-ready" qualities and its versatility, this dredge is the most popular of all types. The dippers usually range in capacity from ¾ to 15 cubic yards. Wherever stumps and rock are encountered, the dipper dredge should be used.

The clamshell bucket is shaped and operated like a clamshell. It is built light and, therefore, is not adapted to heavy work; but as they close tightly they are used in fine or soft, dry material. They are built in capacities of from 1 to 5 yards.

The orange-peel bucket is shaped like one half of an orange. It opens at the end by dividing into quarters or thirds. These buckets are dependent on their weight and leverage for their digging power, hence are not adapted to very hard digging. They are built in capacities of from 1 to 10 yards.

The dragline bucket is rectangular in shape, similar to the dipper, but is operated differently. It is dragged along the place to be excavated and thus filled. It can be used for heavier digging than the clamshell or orange-peel buckets and is used to considerable extent for ditching. This bucket is used with the dragline excavator. It is built in sizes of ½ to 2 or more cubic yards.

Ditches of large size and long length are dug most cheaply by means of dredges. About the smallest ditch that can be dug with a floating dredge is 12 feet at the bottom and 5 feet deep. The cost of moving the dirt with this type of dredge. under favorable conditions, is 8 cents per cubic yard, while under unfavorable conditions, 10 to 12 cents per cubic yard. With floating dredges, it is hard to give much side slope to the ditches, but with a land dredge it is easier. For flat slopes, however, scrapers or a dragline excavator should be used.

186. Ditching with Dynamite.—Dynamite may be used to dig ditches. This subject, however, is of such importance that it is dealt with in a separate chapter under the heading Explosives.

187. Ditch Berm.—A ditch berm is the space between the waste bank and the edge of the ditch. In constructing ditches, good liberal berms should be left. On large-sized ditches, the berm should not be less than 10 feet. If a liberal berm is not left, the weight of the dirt on the ditch bank causes the bank to slough off and fall into the ditch.

In construction of open ditches, it is essential that the ditch be left as clean as possible and the edge of the berm next to the ditch be free from a "roll of sod;" *i.e.*, the sod should be cut off clean at the edge of the ditch, and none of it left to roll down the ditch bank and fill up the channel.

188. Waste Banks.—In most cases, it is desirable that the waste material from the ditch be placed equally on both sides of it. Openings through these waste banks, in order that the drainage water on the land may be let into the ditch, should be left at such points as will best serve the purpose. Too often, there is not a sufficient number of these openings left, and the efficiency of the ditch is lowered while the owner is caused needless expense by constructing them. If the contractor does his work well and the engineer locates these openings, they can be put in at the time of excavation. It is often desirable, with ditches bordering the highway or railway, to place all the waste on one side of the ditch. It is likewise often desirable, when the open ditch is in connection with or borders a small creek or stream, to place the earth all on one side or use it to dam the old channel. These points should be considered at the time the ditch is constructed.

Problems

56. A ditch 1¾ miles long is to be dug 9 feet deep through absolutely level ground, the bottom width to be 12 feet; side slopes, ½:1. What would be the cost of excavating it (*a*) with a dredge at 8 cents per cubic yard? (*b*) with dynamite at 15 cents per cubic yard?

57. A ditch ¾ mile long is to be dug 6 feet deep through absolutely level ground, the bottom width to be 4 feet; side slopes 1:1. If dug by scrapers at a cost of 12 cents per cubic yard, what will be the cost?

Reference

MASSEY, G. B.: "The Engineering of Excavation."

CHAPTER XV

OPEN-DITCH MAINTENANCE

Open ditches, like roads, if they are to remain useful and render the greatest service, must not only be well built but must also be well taken care of. The American people are willing to pay the amount required to get the best type of construction (in some cases, paying more than is necessary for this class of work), but they have not, as yet, shown very much interest in taking care of this first-class construction after they have it. Owing to a lack of the right kind of sentiment, interest in the maintenance of public works is not evidenced by the people. Public officials reflect the same attitude. A small amount of money expended each year, with proper supervision, would keep these works in excellent condition and, in the long run, save considerable money. This is true of open ditches, particularly large cooperative ditches, streams, and rivers. If they are not properly taken care of, they will not render full service, no matter how well they may have been built.

Most large drainage ditches do not have sufficient fall to produce a silt-carrying current, in spite of the fact that they may have been given the most favorable cross-section and the best possible grade. In such cases, provision should be made in advance to remove the silt which is sure to be deposited. The proper way to take care of all ditches is to employ someone to make regular inspections and, during certain months of the year, to make it his business to see that the channel is kept in first-class condition. The landowners emptying their drainage waters into it would be assessed an amount sufficient to cover the cost of this work.

The problem of ditch maintenance resolves itself into two important sets of operations: first, how to prevent deterioration entirely, or keep it as small as possible, and, second, how to repair the damage after it has occurred and restore the ditch to its original condition.

189. Prevention Methods.—Anything that prevents silt from entering ditches or that tends to carry it through without being dropped by the water comes under this head. Methods that prevent the caving of banks can also be included. Engineers have profited by past mistakes in this respect and are now beginning to insist on many things that were not formerly considered necessary.

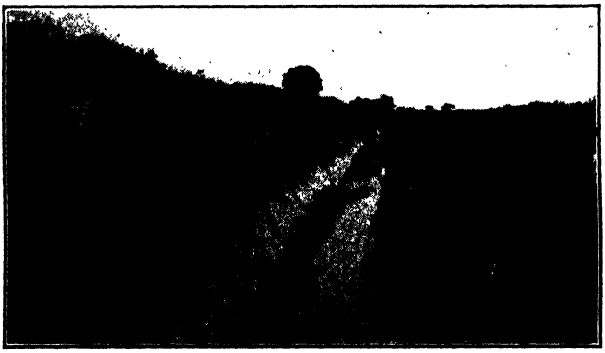

FIG. 90.—It would be easy to clear this ditch when brush first begins to appear.

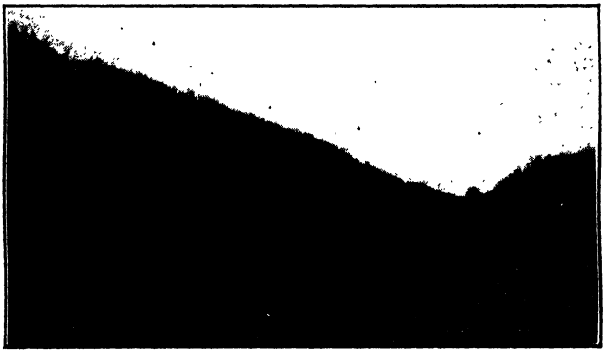

FIG. 91.—The same ditch as Fig. 90 a few months later showing the result of neglect.

190. Soil Washing.—If, by proper cultivation, terracing, or other methods, soil washing from ditch watersheds can be kept under control, much of the silt evil will be eliminated, because silt will not have a chance to get into the ditch. This subject is fully treated in a later chapter and is mentioned here only to show its relation to the problem of ditch maintenance.

191. Diversion Ditches.—The greatest trouble from silting generally occurs where water from upland ditches with steep slopes is emptied into flat ditches in bottom land. The velocity of flow is decreased to such an extent in the flat ditches that the silt settles out rapidly and necessitates almost constant maintenance to keep them open. Sometimes, the trouble is minimized by the use of diversion ditches, running around the lower edge of the high ground, which collect the hill water, highly charged with sediment, and carry it for some distance to a favorable point, where it is emptied into a drainage channel. This protects bottom ditches, to some extent, but the diversion ditch itself needs to be cleaned out occasionally, and its burden of silt generally causes trouble farther downstream.

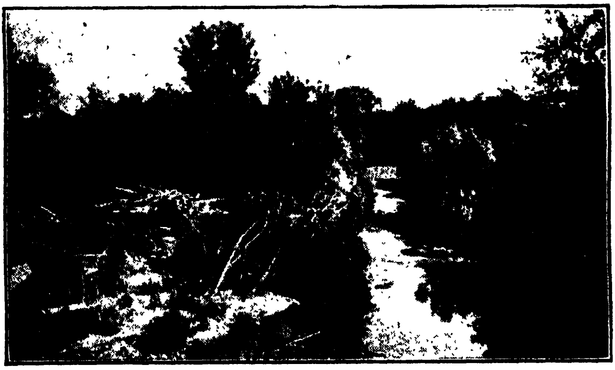

FIG. 92.—Brush obstructions in channel cause increased flood heights and decreased velocity.

192. Settling Basins.—Another method that has proved effective, where the topography permits its use, is to collect the hill water in stilling basins and allow the silt to settle out before the water enters bottom ditches. Frequently, natural depressions and hollows can be utilized for this purpose, but unless there is another into which the water can be turned when one is filled with sediment, they too must be cleaned out at regular intervals.

193. Control of Silt by Flooding.—Still another, and the most sensible way of all, is to treat the silt as a friend rather than an enemy and utilize it to build up and enrich low bottom lands. This method was originated by Roy N. Towl, a consulting engineer of Omaha, Neb., and it has been used by him with much success on one of his farms near Tekamah, Neb., since 1917.

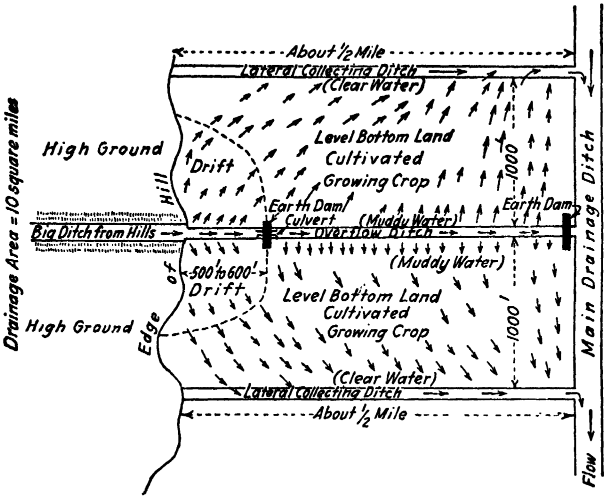

FIG. 93.—Sketch showing method of silt control by flooding. Arrows indicate the direction of water movement.

Rich silt has been deposited at the rate of about 1 foot per year, and the land, formerly sandy and level, has now assumed a

FIG. 94.—The Towl Farm near Tekamah, Neb., in 1916. This was its normal condition prior to silting.

considerable surface slope away from and at right angles to the overflow ditch. Water is caused to spread out in a slowly moving, thin sheet which does not injure growing crops and does not prevent cultivation a short time after it recedes. Good crops are thus produced at the same time that the land is being continually enriched and built up.

Fig. 95.—The Towl Farm just after a 1925 flood had deposited 2 inches of silt. Corn is shown growing at a height of 6 inches.

The accompanying sketch (Fig. 93) illustrates clearly the action that takes place. The central or overflow ditch is made just large enough to take care of a normal flow. Any excess delivered to it from the larger, non-overflow, hill ditch passes through the culvert in the upper dam and is prevented from entering the main drainage ditch by the lower dam. The water continues to rise until it slowly overflows the banks and travels

Fig. 96.—View showing silt deposit just after cultivation.

laterally in both directions, depositing a thin film of silt as it goes. By the time it reaches the lateral collecting ditches, 1,000 feet away, practically all the silt has been dropped, and the water is delivered to the main drainage ditch in a clarified condition. Any drift or other débris that comes down in times of flood is caught by the upper dam and deposited within the small area shown by the dotted line, thus leaving the cultivated land free from trouble in this respect. If the culvert should become clogged, no particular damage would result before the water receded and it could be cleaned out.

FIG. 97.—1925 corn crop "laid by." This corn produced 40 to 60 bushels per acre on the Towl "Silt Farm."

The layout shown in the sketch is suited to take care of the run-off from a watershed of 10 square miles. A larger watershed would require proportionately more land for the water to spread over. Great care is necessary to see that the water thins out uniformly and travels slowly. The bed and banks of the overflow ditch build up at an equal rate so that, in a few years, the ditch flows along the crest of a ridge which may have a lateral slope of as much as 1 foot per hundred.

194. Caving Banks.—There are two common causes for caving banks—either the grade of the ditch is excessive, resulting in erosive velocities, or the side slopes have been improperly constructed and are too steep to be permanent.

If the natural fall of the ground is greatly excessive, the ditches may be designed in longitudinal sections or grades flat enough to produce safe velocities, and the surplus fall can be absorbed in a series of "drops," one at the end of each section, where the ditch bottom and sides have been well protected against scour. Or, if there is only a moderate excess in grade, caving can be prevented by protecting the banks at critical points with masonry riprap, willow mattresses, or brush retards, or by deflecting the current with some form of spur fence or dike. Sometimes, engineers take advantage of moderately high grades to construct the ditches much smaller than necessary and depend upon erosion to enlarge them.

On the other hand, it is not so easy to secure side slopes which will be absolutely permanent in any kind of soil. It is very inconvenient and difficult for floating dredge operators to dig flatly sloping banks, so much so that they prefer to dig the ditches with the prescribed top width but with steeper side slopes and greater depth than specified, with no pay for the extra excavation. Many good engineers in the past have allowed this to be done on the theory that the banks would soon cave and slide just enough finally to cause the ditch to assume the form of cross-section that it was originally designed to have. In some cases, this idea has worked out fairly well, while in others, it has been disastrous. Experience has shown that, in general, it is wise to go to extra trouble and expense to construct the ditches in the first place with smooth side slopes which are flat enough to insure permanence.

As an example of what is likely to happen under the "cut-and-slide" plan, an experience of the Elliott-Harman Engineering Company in one of their districts in the lower Mississippi Valley may be cited:[1]

> A few years ago in carrying out some work in southeastern Missouri we undertook to get the construction done in such a way that there would be a 1:1 slope actually dug in that form, on the assumption that the contractors had been remiss in their previous operations in constructing the ditches that were then to be reconstructed, and that, by reason of that careless work, both on the part of the contractor and the supervising engineer, the ditches had deteriorated unduly. That was the landowner's impression and the generally accepted theory.
>
> So we started out with a very close inspection and, after a few months of work with two or three dredges and a number of miles of ditches very accurately cut in which the dipper was required to cut the bank in a sloping position and not bench it off or leave it partially ragged, we had

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[1] HARMON, JACOB A., *National Reclamation Magazine*, p. 84, Apr. 1, 1925.

> some very pretty ditches standing up beautifully and everybody was happy.
>
> That work was begun in the summer of 1919 . . . and about March 1, 1920, we had reports that some of those ditches had failed very seriously. Within six weeks after the rainy season began, the banks of some of those ditches, carefully constructed with a base width of 15 to 20 feet and 1:1 side slopes, had caved to a serious extent. The material had gone in from the sides and extended entirely across the bottom so that the ditches had filled from 3 to 6 feet above the excavated grade, which ranged from 10 to 15 feet in depth . . .
>
> . . . This led to the conclusion that, in order to have stable banks, the slopes of the ditches must be flattened. In other words, we must excavate the ditches with such flat side slopes that the sliding and caving would not begin and, if we could find that safe slope, our ditches would be secure . . . As a practical solution of this problem, where about 200 miles of construction work was underway, we decided to use slopes of 3 horizontal : 1 vertical. That makes a considerable increase in excavation, especially where the ditches were excavated through ridges and had a large surplus cross-section above the actual carrying section of the ditch. But, on the other hand, at places where the cross-section of the ditch as excavated was figured to flow full in the lower ground, the flatter side slopes did not increase the excavation a very great deal. Here the entire cross-section is carrying section and the hydraulic elements of the three to one slopes are reduced only a comparatively small amount from the 1:1 slopes . . .
>
> The practical effect of this work has been very satisfactory . . . The slopes of the ditches are being planted with Bermuda grass for protection against gullying by rain . . . Farmers can go on a slope of 3:1 with a mowing machine and a team and can cut the growth from it . . . If we construct works so that farmers cannot use their own equipment for maintenance, then the ditches deteriorate without any attention until they are in such bad condition that they must be reconstructed at great expense . . . The point I wish to emphasize is that, by the use of flat side slopes, even though they entail 15 to 20 per cent additional excavation, actual economic savings to many of our drainage districts may be effected.

It should be said that the soil in the region just discussed is an exceedingly fine-grained, black clay, commonly known as *gumbo* or *buckshot*. When wet, it seems to lose all its cohesive structure and melt away, sliding in layers along lines of cleavage almost horizontal. This is in sharp contrast to the behavior of the more common, coarser clays, found in the upper Mississippi Valley and elsewhere. These clays cave by breaking along nearly vertical lines and roll or slump down into the ditch bottom. Such clays will stand up very nicely on slopes of 1:1 or, sometimes, even as steep as ½:1.

On recent reconstruction work in the Little River Drainage District, a $7,000,000 project also in southeastern Missouri, the Morgan Engineering Company used side slopes of 1½:1 and, on deep ditches, 2:1 with apparent success.

Perhaps a majority of land in the lower Mississippi Valley is composed of alluvial silt deposited over fine, water-bearing sand. The only safe way to proceed in such soil is to keep the ditches shallow enough to avoid penetrating the sand which, otherwise, would flow into the ditch in large quantities, undermining the surface layers of silt and causing them to drop into the cavities thus formed. If ditches of reasonable depth cannot be secured in this way, the work must proceed very cautiously and slowly, the sand being excavated in thin layers and sufficient time allowed between the removal of each layer for surplus water to drain away. Flat side slopes are also necessary.

Ditch slopes sometimes fail by bulging out, due to the pressure or weight of the excavated material, which has been placed too close to the edge. For large ditches, dug under normal conditions, a clear space, or berm, of at least 10 to 20 feet should be left between the edge of the ditch bank and the inner toe of the spoil bank on either side.

195. Restoration Methods.—After ditches have been allowed to deteriorate for a number of years until the point is reached where they no longer carry the water satisfactorily, reconstruction, in whole or in part, is the only thing that will restore their original efficiency. This is always very expensive and is an operation beset with many difficulties.

196. Clean-out Work.—If the side slopes and banks are in good condition, ditches in flat country can sometimes be restored by cleaning out the accumulations of silt deposit. Many agitating devices, intended to stir up the mud and cause it to be flushed out, have been proposed, but none has proved very practical or effective, chiefly because the fall is insufficient. In general, the best way to remove such a deposit is to excavate it with one of the several types of well-known excavating machines.

Floating dredges cannot be used unless the depth of mud exceeds 2 feet, because there would not be enough water to enable them to float. Such dredges usually dig downstream and hold water against the banks for long periods of time. This softens the slopes and may cause them to cave badly when the water finally goes out with a rush.

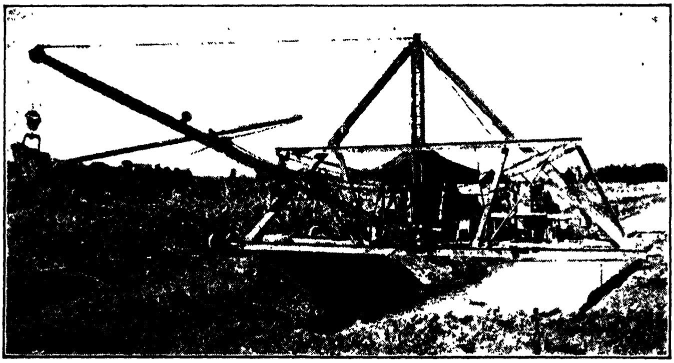

FIG. 98.—A land dredge, ¾-cubic yard capacity dipper, 40-foot boom, 43-foot gauge. It is a popular type of machine for clean-out work.

Light dipper excavators (Fig. 98), powered by internal-combustion engines and mounted on platforms which straddle the ditch, are admirably adapted for such work. They are propelled on flanged wheels and track sections or on rollers or skids and dig upstream.

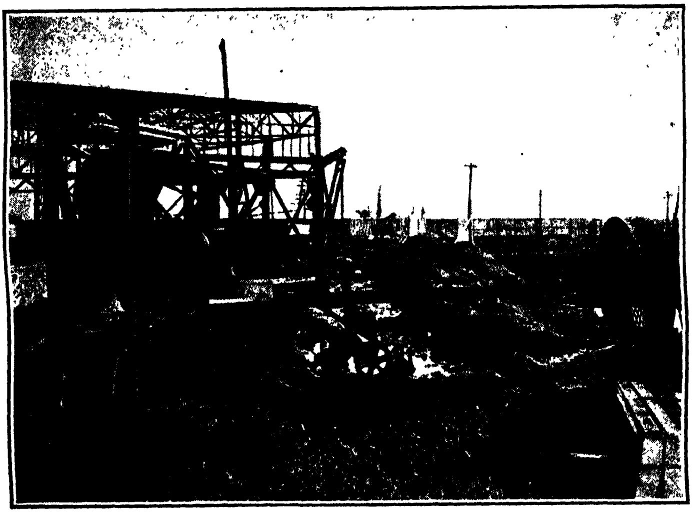

FIG. 99.—Another type especially designed for clean-out work. (*Courtesy of Pawling & Harnischfeger Company.*)

Draglines are also popular and efficient machines for this class of work. They move along either berm on caterpillar treads or on "walkers" and are capable of excavating the bottom cleanly and of cutting smooth side slopes at any angle desired. Draglines can excavate ditches with ease up to 125 feet bottom width.

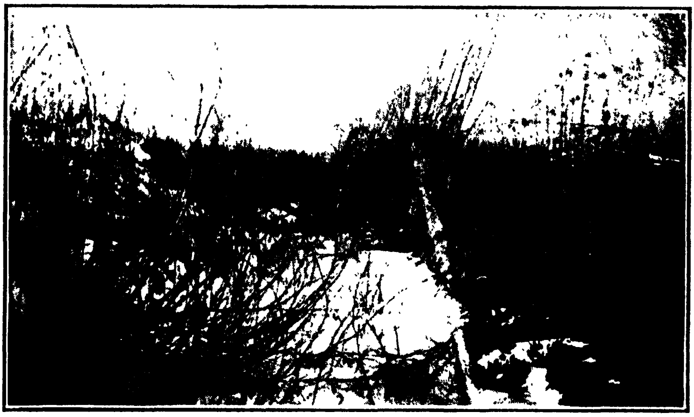

FIG. 100.—A ditch in Racine County, Wisconsin, partially choked with silt and brush.

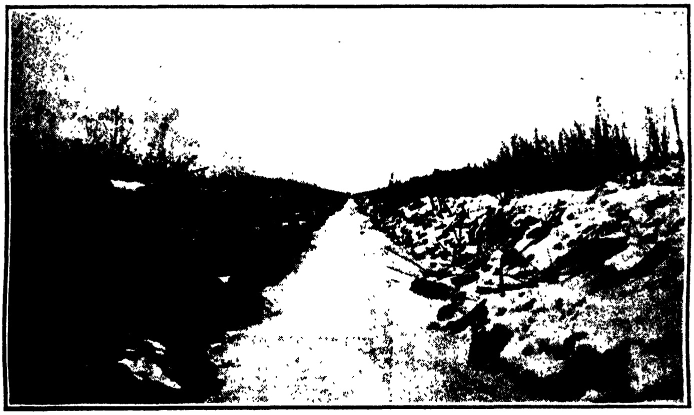

FIG. 101.—The same ditch as in Fig. 100 after cleaning with explosives.

In exceptional cases, where it is necessary to spread out the excavated material at considerable distances from the ditch, machines operating on the hydraulic principle have been used to advantage.

For several years, machinery manufacturers have been attempting to develop a machine designed especially for cleanout work, but so far, nothing has been introduced that has proved superior to the other types. One such machine is shown in Fig. 99.

If the volume of silt to be removed is too small to warrant the employment of excavating machines, the use of explosives has been found quite practical and effective (Figs. 100 and 101). Perhaps this method has reached its highest state of development in Wisconsin under the direction of John Swenehart of the University of Wisconsin. It is important to place the charges in just the proper position in order to secure a clean job and stable side slopes. This point, as well as the strength of the charges and their spacing, can best be determined by making a few preliminary experiments. Figure 102 illustrates the position of the cartridge to produce a desirable V-shaped bottom, and the photographs show how satisfactorily results can be secured with proper management.

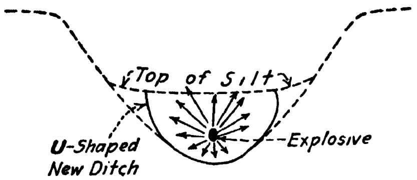

FIG. 102.—Ditch cross-section showing proper position of explosive and how it acts.

197. Enlarging Outlets.—Experience has frequently indicated the desirability of increasing the capacity of outlet ditches at the same time that the clean-out work is being done. This is sometimes accomplished by deepening, but if there is danger of encountering quicksand at greater depths, the increased capacity had better be secured by widening. This generally consists of removing the slope and spoil bank on one side and is often quite tedious work on account of buried logs and stumps.

A novel method, used by the Morgan Engineering Company in their work in Missouri, was to carry the run-off from distant areas in one or more "high-flow-line" ditches where the water was confined between tight spoil banks. Lateral drainage of land in the vicinity was taken care of by parallel "low-flow-line" ditches.

198. Tributary Inlets.—Wherever water enters a main canal from tributary channels, either tile or open ditches, it should be admitted through specially constructed inlets. These need be nothing more than pipes or culverts whose flow line at the outer end is the same as the grade of the main. Sometimes, when the ditches are patrolled regularly, it is permissible to discharge an open-ditch lateral through a section, dug on a smooth grade at least 100 feet long, joining the bottom of the lateral to the bottom of the main. In no case should an overfall be permitted, as this always causes a scour in the main ditch directly beneath and the formation of a bar just below. Water from laterals should be discharged in the direction of flow of the main ditch. Improper inlets are a common source of trouble in open ditches.

199. Vegetation.—Weeds and rank vegetation can hardly be prevented from growing in ditch rights-of-way above the water line, and aquatic plants persist in growing underwater in slowly moving streams of normal shallow depth. Mowing machines, scythes, sickles, brush hooks, and axes should be used at frequent intervals to keep the banks clear, but cutting vegetation from the bottom and sides is a more difficult undertaking. Where there is a perceptible current, long, pliable bandsaws, weighted to hug the bottom and drawn back and forth while moving upstream diagonally, have been used to advantage. Men should be stationed below with pitchforks to catch the floating stems and throw them out.

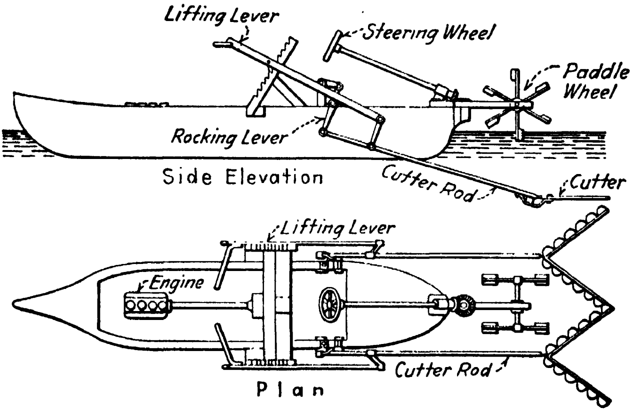

FIG. 103.—Power driven weed-cutter on motor boat.

Another device which has been used extensively in England and also in India, Egypt, and Australia is described as follows:[1]

> An English device for clearing rushes, water-lilies, weeds and other growth from drainage and irrigation ditches, rivers, lakes and ornamental waters consists of power driven cutters operated from a small motor boat of 12-inch draft (see Fig. 103).
>
> Each cutter consists of a steel blade, V-shaped in plan with a wavy or scalloped cutting edge and having the apex attached to a long rod. There is a rod on each side of the boat, the upper end being attached to a rocker arm and also to a link on a lifting lever by which the cutter is raised and lowered as desired. The rocker mechanism is driven from the launch engine and, as the boat moves forward, the cutters are given a rapid oscillating motion, so that they engage the weeds at high velocity and strike them with a diagonal cut.
>
> In shallow water the cutters trail on the bottom, being provided with spring shoes to keep them out of the mud and to guide them over logs or other obstructions. In deeper water they are set usually to cut at a depth of 4 to 6 feet. It is stated that, in ordinary service, the boat will clear as much as 4 acres in an hour. A small double paddle wheel is used for propulsion as it will not be clogged with the weeds. This wheel serves also as a rudder, being carried by a pivoted frame which has a radial movement in a horizontal plane. For small ditches a rowboat or a scow pulled by tow lines may be fitted with a single, hand-power cutter, the oscillating mechanism of which is operated by a crank handle.
>
> This weed-cutting device is built by the Saunderson Tractor and Implement Company, Bedford, England.

200. Poison.—In some localities, woody growth, such as willows and other young trees, predominates. Very soon after cutting, young shoots sprout from the old stumps and grow rapidly, thus necessitating recutting within a short time. In the attempt to prevent such sprouting, O. C. Kulicka, a drainage engineer of Greenville, Miss., has experimented with various chemicals which were intended to destroy all the live tissue of the stumps and roots. He found that a solution of granulated caustic soda and white arsenic, 10 pounds of each dissolved in 8 gallons of water, proved most effective. After the mixture cools, 2 more gallons of water are added, and the compound is applied to fresh cuts and splits in the stumps by means of a homemade mop. The cost of this work averaged about $10 per mile, and the rate of progress for a crew of eight men was from ½ to 3 miles per day, working on a ditch of 125 feet base width, with a very dense growth. On smaller ditches, only three or four men were used.

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[1] *Eng. News-Record*, Vol. 89, No. 4.

Great care must be taken not to inhale or swallow any of the dust or poisonous fumes arising while the preparation is being made, and all stock should be kept away for at least 10 days from ditches undergoing this treatment. Vinegar, or some other acid, acts as an antidote in case of accident.

201. Spoil Banks.—The spoil or waste banks of the ditch are very difficult to take care of. They are usually large and irregularly placed and, in many cases, are composed of fertile soil. If it is feasible to level these off, it should be done, provided there is no need of additional waterway. If it is not possible to level them, they should be so dealt with as to prevent the growth of weeds, whose seeds would be scattered over cultivated fields and carried to other parts of the country on the drainage waters.

202. Bridges.—Substantial bridges should be placed over all drainage ditches. These bridges may be made of wood, preferably treated with creosote or some other preservative, but it is better to use concrete culverts or steel bridges to keep down the cost of maintenance. Creosoted-wood bridges, however, with strips of sheet iron bolted along the treads of traffic have proved satisfactory in some localities. In any event, the abutments and floors of these bridges must be carefully examined at least twice a year, and such repairs as are necessary should be made at once.

203. Costs.—Very little data are in existence regarding the cost of maintaining open ditches. Conditions differ so widely that it would be impossible to prepare a set of figures which would apply everywhere, even if such data were at hand.

As a general rule, for clean-out work, the cost per cubic yard will run from three to five times the unit cost of the original excavation, largely on account of the smaller volume to be moved. In Iowa, this cost has run as high as $900 per mile for moderate-sized ditches.

The following tabulation[1] (Table 22) is a record of maintenance costs for both open ditches and tile drains, on one of the government irrigation projects in the West. It covers a period of about 4 years and gives a general idea of how the various items run and their relation to each other. The ditches, of course, are relatively small, as compared with similar structures in humid regions.

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[1] Taken from *Reclamation Rec.*, January, 1922.

TABLE 22.—MAINTENANCE COSTS OF DRAINAGE DITCHES

	Minimum		Maximum		Average	
	Cost per mile-year	Per cent	Cost per mile-year	Per cent	Cost per mile-year	Per cent
	Drainage ditches					
Patrolling	$ 0.90	3.26	$ 13.03	6.6	$ 6.10	8.5
Clearing weeds and debris	8.35	20.20	17.71	9.0	17.96	25.0
Clearing silt and slips	1.58	5.50	22.55	11.5	16.32	22.7
Repairs to structures	12.36	43.30	89.05	45.4	11.63	16.2
Minor expenses, plant and equipment	1.18	4.1	14.53	7.4	3.90	5.4
Miscellaneous*	0.26	0.9	....	....	0.96	1.3
Unit field cost per mile-year	24.65	.....	156.89	....	56.87	
Overhead	3.91	13.70	39.38	20.0	14.76	20.6
Total unit cost per mile-year	28.56	.....	196.27	....	71.63	
	Tile drains					
Patrolling	......	.....	....	....	0.53	0.9
Clearing tile and trap boxes	5.96	68.8	24.24	24.3	14.72	25.0
Repairs to tile and trap boxes	0.36	4.2	37.56	37.6	31.00	52.6
Minor expenses, plant and equipment	......	.....	1.24	1.3	2.54	4.3
Replacement of drains	......	.....	....	....	2.15	3.6
Hydrometry	......	.....	....	....	0.01	
Unit field cost per mile-year	6.32	.....	63.05	....	50.95	
Overhead	2.33	27.0	36.76	36.8	7.98	13.5
Total unit cost per mile-year	8.65	.....	99.82	....	58.93	

204. CCC Drainage Camps.—In 1935 it was decided to assign 45 Civilian Conservation Corps Camps to the U. S. Bureau of Agricultural Engineering to be used for maintenance work in organized drainage districts. This has provided much-needed impetus for drainage maintenance and has resulted in important benefits to the public by providing better outlets for all kinds of private drains. The actual work itself, however, has been strictly limited to public projects duly organized under the various state laws.

The first camp was located at Bancroft, Kossuth County, Iowa and the following record of work accomplished by this one camp during its first 3 years is cited as typical.

Clearing: 3,210,536 square yards requiring 46,456 man-days.
Excavation: 2,225,993 cubic yards requiring 15,475 man-days.
Tile work: 64,343 linear feet requiring 9,674 man-days.

The commercial value of this work is estimated to be $614,711.

Problem

58. A ditch 1 mile long traverses flat land on a grade of 0.3 feet per mile and carries surface drainage from higher ground. The ditch dimensions are: side slopes, 1:1; depth, 6 feet; bottom width, 10 feet.

A storm occurs at a time when the discharge rate is 10 cubic feet per second. Five hours after the first increase occurs the ditch is flowing full and remains at bankful stage for 5 hours, after which the flow decreases during a period of 10 additional hours to the original rate of 10 cubic feet per second.

The dry weight of silt contained in each cu. ft. of inflow water is 3 lbs. which is reduced by sedimentation to 0.5 pound at the outlet.

Take arithmetical averages during the rising and falling stages as sufficiently accurate for computing total discharge and assume 50 lbs. of dry silt equivalent to a volume of 1 cubic foot when wet.

If the silt is uniformly distributed lengthwise throughout the ditch,

(*a*) How deep is the deposit resulting from this one storm?

(*b*) By what percentage is the discharge capacity of the ditch reduced?

CHAPTER XVI

EARTH DAMS AND LEVEES

205. Earth Dams.—A dam erected across the width of a gulch, coulee, gully, or valley will form a reservoir in which may be stored sufficient water for the various purposes of the farm. A stream flowing through the coulee or valley may supply the necessary water, or the run-off from the slopes adjacent to the reservoir, or both, or some external source may be depended upon for the supply. The magnitude of the reservoir is, of course, dependent upon the area drained and upon the site available for storage purposes. The present object is to consider the individual farmer's need; therefore, only the small earth dams will be discussed.

The earth dam is relied upon in all sections of the country as a means of impounding water to irrigate small tracts, to water stock, etc., also to eliminate gullies and to levee land against overflow. It lends itself to all these purposes very readily and is easily and cheaply constructed.

The results obtained from poorly constructed earth dams in this country have been surprisingly good. In many instances where failures have occurred, however, the fault may be traced directly to poor construction. There are a few general principles, which, if followed, insure a safe and durable structure. The first and most important consideration in earth-dam construction is that the dam be made as nearly impervious to the action of water as possible. Seeping water is destructive in several ways, among which the following two are most important: (1) The saturation of the dam imparts an effect of buoyancy which lessens the effect of gravity, upon which, in a large measure, the stability of the dam depends. (2) The cohesion of the soil particles in the dam is destroyed. Water acts as a lubricant upon which the soil particles will slide one over another—this is a common cause of failure. Seepage may occur at any or many points along the dam. Once started, the volume of seepage water increases rapidly, and erosion will result.

In sections of the country where timber is plentiful, the log dam, illustrated in Fig. 104, is inexpensive and easy to build. It consists of alternate rows of logs, 6 to 8 inches in diameter, placed at right angles to and parallel with the current and about 3 feet apart. Some adze work is necessary to notch the logs and trim them to a good fit at all points of contact. The upstream face is made preferably of dimensioned timber laid close together to form an inclined platform. The low end of the platform is carried well into the stream bed and is anchored down with a clay and gravel fill, as shown. A short horizontal platform is spiked under the overfall to prevent undermining by scour.

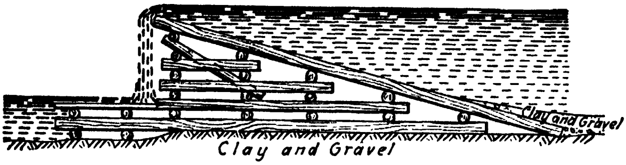

FIG. 104.—A simple log or timber dam, cheap and easy to construct. Suitable for raising the water level of a flowing stream from 2 to 4 feet.

206. Types of Earth Dams.—The types of earth dams in general farm use are three in number—puddle core-wall dam, impervious water faced dam and homogeneous dam.

207. Puddle Core-wall Dam.—The puddle core-wall dam is an earth-filled dam which has a core wall in the center, this core wall being made of puddled earth. The advantage of this type of construction is that the core wall presents an impervious barrier to seeping water. Its use is restricted to those conditions under which a limited amount only of good puddling material is available. The best material is put into the core walls and upstream part of the dam. The size of the core wall varies, the top being from 4 to 5 feet wide, with the bottom width one-third the depth or wider; uniform batter on both sides. The wall

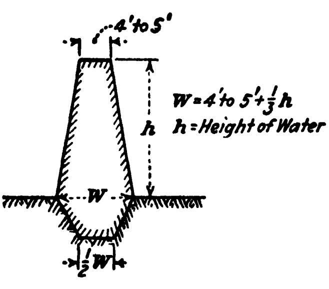

FIG. 105.—Dimensions of puddle core wall.

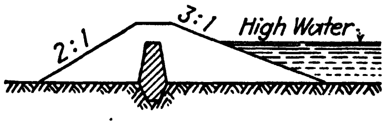

FIG. 106.—Position of core wall in earth dam.

goes into the foundation 4 to 5 feet, and this is battered to about one-half the width at the ground level, as shown in Fig. 108. The position of the puddle walls should be through the center of the top of the dam, as shown in Fig. 109.

The method of making and placing the puddle should be given careful attention. The material used for the core wall should be as impervious as possible. Clay is, perhaps, the best, but if there is not a sufficient amount available for the entire core, it may be mixed with other materials. The material must be well graded; *i.e.*, the gravel should be well mixed with the sand, and these together mixed with the clay in order to have all voids (air spaces) filled. The voids in any material can be found by taking a sample of the material and drying it out, then pouring water into the vessel containing the material until the water comes to the surface, the amount of water poured in is equal to the amount of voids. By mixing the different materials, you can finally obtain one that has a maximum density or, in other words, one that has the smallest amount of voids. This is the kind of material to use for the puddle. Mix it with just enough water to make it thoroughly pasty, then place it in the dam in 6-inch layers and tamp it well. Sometimes one material can be found, sometimes another; therefore, it is difficult to give any direct proportions that will be of general use in making a mixture.

H. M. Wilson offers the following as a rough guide:

	Cubic Foot
Coarse gravel	1
Fine gravel	0.35
Sand gravel	0.40
Clay gravel	0.25

This mixture would give 1.7 cubic feet, and when it is well worked together with water and thoroughly tamped, it reduces to about 1.25 cubic feet.

The balance of the dam and its foundation should be prepared and constructed the same as for the homogeneous dam.

208. Impervious Water-faced Dam.—This form of dam is used when there is a sufficient amount of impervious material at hand to build one-third to one-half of the dam. The material is placed on the upstream side, and considerable care is exercised in its placing. The balance of the dam, or downstream side, is built of coarser material which will supply the necessary stability that comes from mass. It has additional merit in that it will offer good drainage, should there be any seepage.

209. Homogeneous Dam.—Refer to Fig. 107. The homogeneous dam is made of the same kind of material throughout, which gives it the same consistency in all its parts. If there is any difference in the grade of material, the better, or the more impervious, material should be placed in the upstream side of the dam. If an impervious clay is not available and it is necessary to use a mixture, then the material should be graded in the same way as explained for the core-wall dam, and the best mixture obtained.

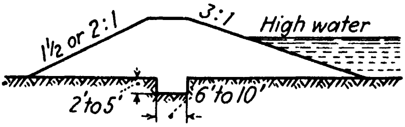

Fig. 107.—Homogeneous earth dam.

210. Construction.—In placing the material in the dam, it should be put in in thin layers and well tamped. It should be moist enough to tamp well. This may be accomplished by turning the water from the stream into the borrow pit, or, if this is impracticable, advantage may be taken of the rainy season, and the earth moved after the rains have wet the pits. In using borrow pits, the sod must be removed to a depth of 5 or 6 inches and wasted. *No sod or organic material of any kind should go into the dam.* Borrow pits must never be taken from below the slopes of the dam produced, as here they will collect water and hold it, causing the foundation of the dam to become saturated. The borrow pits above the dam must be at least 10 feet from the toe of the structure; this is to prevent weakening of the foundation. Never make pits deeper than 3 or 4 feet. The use of common wheel scrapers is considered good practice. Some engineers, however, are advocating the four-horse Fresno scrapers, as they are more easily handled, and the dirt can be placed in thin layers. The tamping should be well done. Horses are good, if used enough. There is a tendency, however, to rush the work and not do it thoroughly. Some builders have driven goats or sheep back and forth over the earth to good advantage.

In building the dam, make allowance for shrinkage of earth. Usually about 10 per cent is allowed, though this figure is subject to a wide variation.

211. Foundation.—The foundation should be carefully looked into in choosing the site for a dam. The requirement for the foundation is that it must not allow seepage under the dam. The degree to which the soil is impervious is the measure of its desirability as a material for the foundation. A tight clay or a mixture of sand and clay are, perhaps, the best materials to have. Less desirable materials are the clayey loams, sandy and gravelly loams, sand and gravel soils. The last two, unless they are impervious, or can be made so through the addition of clay, should not be used—soft marsh soils are not at all desirable. Where shale, slate, and bed rock are available, they may be used, but it is necessary to take extra precaution to break up the line of cleavage between the dam and the foundation. This is done by means of trenches. If it is not done, there is danger of seepage along this line.

The preparation of the foundation before building the dam should be done carefully and conscientiously.

First, the sod, stumps, and all other growth should be removed to the depth of 5 or 6 inches, thus removing all the organic matter. The surface, then, should be thoroughly plowed and disced in order to give a good bond between the dam and the foundation.

Next, excavate the trench. The material from this excavation can be placed in the downstream toe of the dam. The size of the trench will be governed by the type of dam. If a core wall is to be placed in the dam, the dimensions given elsewhere will apply. If a homogeneous dam is to be built, however, it is just as necessary to have a trench running parallel with the axis of the dam, as shown in Fig. 110. This trench is from 6 to 10 feet wide and from 2 to 5 feet deep. Its purpose is to tend to make the dam more impervious by breaking up the outline of the foundation.

212. Dam Design.—The design of a dam calls for some little study and investigation, as not only is the selection of the type involved, but also it is necessary to determine the dimensions for the complete structure. It is common practice to start at the top of the dam and design down. If a roadway is to be made on top, then the top width should be selected accordingly. The minimum top width for low dams is from 8 to 10 feet; this minimum width, however, increases with the depth and runs as high as 20 feet for dams with 30 feet of water. The slope on the upstream side should be at least 3:1; *i.e.* a "run" of 3 feet for each "rise" of 1 foot. The slope on the downstream side should never be less than 1½ feet: 1 foot; and 2:1 is much better; while even 3:1 is sometimes used.

The distance between high water and the crest of the dam should be from 3 to 5 feet. The reason for this is to prevent frost from loosening the top section of the dam and thus offering a frost crack for the water to seep through. The wave motion must also be taken into account, and a sufficient height allowed so that the waves will not wash over the dam. The additional height also adds a factor of safety, should the spillway not be ample.

213. Wasteways.—The wasteways or spillways must be given careful attention, as many dams, otherwise carefully built, have failed because of an insufficient wasteway to carry off the floods. There are several ways of providing the wasteway. One is by taking advantage of the natural channel, if this is not too near the dam. This is considered a good method, because it is cheap and keeps the surplus water away from the dam. The more common method used to obtain the same result is by putting a canal or ditch around one or both ends of the dam. Care must be used in constructing this form of wasteway to prevent washing out of the dam. It is well to construct levees on the sides of the canal next to the reservoir. These levees should extend well past the toes of the dam and should be about 6 feet on top, with the slope next to the reservoir 3:1, while the slope on the inside of the canal should be at least 2:1.

In constructing this canal or ditch, if a natural, sodded depression can be taken advantage of, so much the better, as the sod will prevent washing. If this cannot be done, then the canal should be excavated from solid earth. Never excavate the wasteways through the dam, unless it is to be lined with concrete or masonry as this will cause the dam to wash out. The water in the wasteway should not be given a sudden drop or too large a grade without taking precautions against erosion. If a vertical fall is to be given, its base should be filled with rock, or a complete concrete or wooden fall built. If these precautions are not taken, great gullies will occur in the wasteway, and soon the dam will be endangered. The size of the wasteway should be amply large. Always err on the side of safety. Wasteways are usually made with the bottom from 3 to 5 feet below the top of the dam and from 10 to 40 feet wide, depending entirely upon the size of the floods to be taken care of.

214. Dam Outlets.—The dam outlet is used to carry the water through the dam in order to have it available for irrigation or stock use. The size of the outlet is dependent upon the quantity to be used at any one time. The size in general use for small earth dams is from 6 to 8 inches. The materials used in the construction of these outlets are wooden boxes, cast-iron pipes, wrought-iron pipes, and tile. The wooden box is undesirable, because it is not durable, is expensive in some sections, hard to lay together, and does not lend itself to the settlement of the dam. The wrought-iron pipe is more flexible, is easily laid, and has a life of about 25 years. The vitrified tile is easily laid, has long wearing qualities, and is cheap. The main objection to it is that it comes in short lengths and in the settlement of the dam is liable to open at the joints. If care is taken in laying it, however, and the joints are filled with a cement mortar, of a mixture of 1 part cement:1 part good clean sand, this difficulty may not prove serious. This form of vitrified tile will stand a water pressure of from 10 to 20 feet without danger.

The valve for the outlet is best placed in the upstream face of the dam, thus keeping the water out of the outlet when not in use. The common gate valve for this purpose gives good satisfaction.

In laying the outlet, cutoff walls should be placed along the pipe. These consist of square collars built around the pipe and made of thin slabs of concrete about 6 inches thick, from 1 to 2 feet wider than the pipe, and spaced about 10 feet apart. They are used to prevent seepage along the line of contact between the earth and the pipe.

215. Wave Protection.—The protection of the dam from wave action can be accomplished in several ways. If rock is available, a rock face can be placed on the upstream face of the dam, or just that part exposed to wave action. This *riprap,* as it is called, should be placed in a bed of sand or gravel, in order that the voids in the rock may be filled and not allow the action of the waves to reach the earthen part of the dam. Brush may also be used for this purpose. The brush is put on in layers and anchored with rock or logs laid on top. This method, however, is only temporary and needs constant repairing. In some cases, willows are woven into mats and placed on the dam. Board fences are also used to some extent. They are built to receive the action of the waves and keep the moving water away from the dam. A much better way, where possible, is so to locate the dam that the prevailing winds blow away from it, situating it in such a way that the waves do not wash it and make wave protection necessary.

216. Cost of Dam.—The cost of the earthen dam varies greatly with the local conditions and the type of dam. An approximate cost would be from $3 to $50 per acre foot of water impounded. The most accurate method of estimating the cost of a dam is to get a set of cross-section levels of the dam site; this, together with the design of the dam, will allow the cubic yards in the dam to be figured. The local cost, per cubic yard, of moving dirt times the yards in the dam will give the total cost of earthwork. To this, of course, must be added the cost of preparing foundation, outlet, wasteway, and wave protection.[1]

217. Levee.—A levee is a long dam, usually built of earth, constructed along one or both river banks or along the shore line of the sea to prevent the land adjacent to the sea from being overflowed when the water rises above its natural banks.

In determining the feasibility of the leveeing of a certain tract of land, the benefits must be determined as well as the cost of the project. The two amounts should be balanced one against the other, and only when the benefits exceed the cost should the levee be built. The cost will include not only the total cost of constructing the levee but also the cost of handling the surplus water on the leveed land, which includes the rain water and any other water which may come from the hills. This is usually handled by means of pumps. Sometimes the land reclaimed is so low that the pumps must be operated most of the time, while there are also conditions which would require them to be operated only during certain parts of the year. Besides the cost of installing a system of drainage to get the water to these pumps, the operation and maintenance expense must be taken into account.

It can readily be seen that the cost of providing drainage for a tract of land calling for levees is very high.

218. Levee Location.—The location of the levee must be given careful consideration and considerable investigation in order that it may not fail either through poor foundation or insufficient channel. The levee should be located on stable ground with subsoil as impervious as possible. It should be placed where good material for its construction is close at hand. There should be sufficient room left on the stream side, between river and levee, to allow for borrow pits. The entire line of the levee is usually parallel to the stream and free from any sharp turns. It is just as essential that the levee should have easy curves as it is for this type of curve to be used in ditch construction. All sloughs and depressions should be crossed on the shortest lines. The levee should be so located that it will not be exposed to strong currents. The distance between the levees should leave sufficient space for flood waters. The high bank of the stream on one side may be used as the levee if the levee on the opposite side is placed back a sufficient distance to take care of the flood waters.

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[1] For an excellent discussion of this subject see *Univ. Kentucky Circ.* 317, "Earth Dams for Farm Reservoirs," August, 1938.

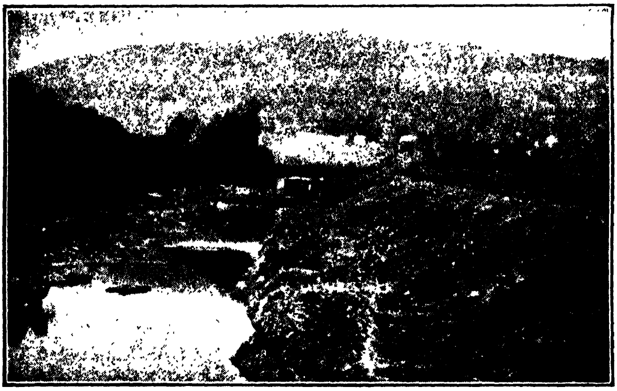

FIG. 108.—A levee under construction by a drag-line machine showing borrow pit and berm.

219. Levee Design.—The usual shape of the levee is trapezoidal, with its top at least 3 feet above high-water mark. The top width should not be less than 6 feet. A common rule offered for this top width is to make it twice the square root of the height. The usual side slopes of the levee are 3:1 on both sides. Where the soil is heavy, however, and the water remains on the levee only a short time, it is possible to use a 2½:1 slope; in no case, however, should the slope be less than 2:1 on the water side and 1:1 on the other. It is poor economy to endeavor to save money by using steep slopes on levees. Sandy material and any other material subject to wave action call for flatter slopes than are given in other cases.

220. Levee Construction.—The preparation of the foundation for the levee as well as the type of material to use are similar to these discussed for earth dams. Hence, that discussion will answer for levees. While the methods of construction of the levee are the same as those used for open ditches and earth dams, the local conditions will have a great deal to do with the method to be used. In some cases, it is necessary to place the levee on a foundation which is not altogether satisfactory in that there may be seepage under the dam which would cause boils or seeps. This situation is taken care of by what are known as *muck ditches*, which consist of ditches from 4 to 6 feet deep excavated under the center line of the levee and filled with puddled earth. This will act as a barrier to seepage water and prevent it from going through from the river to the leveed land.

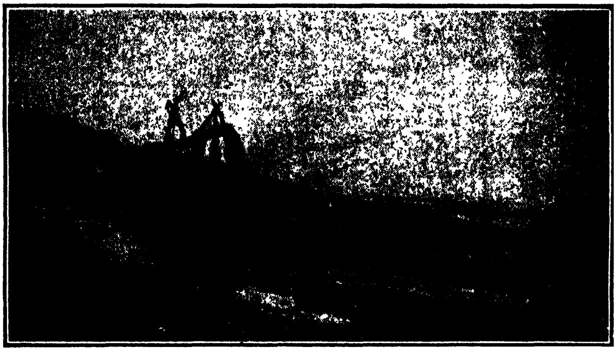

FIG. 109.—A levee being formed near Muscatine, Iowa, by the discharge from a hydraulic or suction dredge.

221. Levee Maintenance.—The levee slopes must be kept smooth and well sodded. Perhaps the best sod for this purpose is Bermuda, where it can be grown. It is desirable to mow the levee at least twice a year in order to cut all the weeds and keep the grass under control. As a general thing, it is profitable and desirable to pasture the levee, as this tends to keep the grass and weeds down and the levee in good shape. Any small damage that might be done by the stock as a result of this would be more than offset by the benefits derived. The top of the levee is sometimes used as a road. This is not desirable, but if it must be so used, care should be taken to see that ruts and depressions caused by traffic are kept filled. Constant vigilance is necessary in the matter of burrowing animals. They should be fought at all times of the year in order that the levee may be serviceable when needed. Where the levee is exposed to a strong stream or wave action, measures should be taken to prevent erosion. Some of the means employed are the planting of brush or trees on the berm, also on the bank between the river and the borrow pits; board fences as well as willow mats and riprap are used for the same purpose. It is desirable that the levees receive periodical inspection in order that any small repairs may be made as soon as possible, thus reducing the danger of serious damage to the leveed land from a flood.

222. Internal Drainage.—The water which flows from the hills adjacent to the leveed lands should be kept off the leveed lands. This is done by the use of diversion ditches. They are usually placed at the base of the hills and emptied into drainage ditches, small streams, or rivers which empty into the main river. As they run with the river, they usually have less fall than the stream into which they empty; hence, there is a tendency for them to silt up. This tendency should be watched, and silt basins put in, or the ditches regularly cleaned. It is best to levee the land on three sides, taking care of the water on the fourth side by diversion ditches. It is necessary, then, only to arrange to take care of the rainfall on the leveed land itself. This water is collected in basins close to the levee and pumped over it by means of pumps or held until such time as it may flow under the levee through flood gates.

223. Flood Gates.—Flood gates are of two different kinds—those manually operated and those automatically operated (Fig. 110). Woodward[1] has the following to say about the merits of each type and their construction:

> In the case of districts where the river falls low enough during the latter part of the summer to afford an outlet for gravity drainage, sluiceways, so arranged that they may be opened when desired, should be built under the levee near the pumping plant. The sluice should be composed of one or more parallel pipes laid nearly level and provided with suitable valves. The length of the pipe will usually be 100 feet or more. Metal, concrete, or vitrified sewer pipe may be used in their construction. Both ends should be protected with strong concrete bulkheads, and cutoff walls should be placed around the pipes at intervals along their length to prevent seepage along their exterior surfaces. Cracking and failure of these cutoff walls and bulkheads, one of the commonest causes of failure in drainage districts, show that they must be made with special care, amply deep and of liberal dimensions. If the outer end of the sluiceway is not below the water line of the river, the bottom of the channel through which the water will flow beyond the

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[1] U. S. D. A. Bulletin No. 304.

end of the pipe should be protected from washing out by riprap, paving or a concrete floor carried to a safe distance. Where feasible, this protection should extend below low water line.

The sluiceway should be sufficient in size to discharge in 24 hours such an amount of water as would cover the whole drainage area ¼ inch deep. In making this calculation the velocity of water through the sluiceway should not be assumed to be greater than 5 feet per second. The sluiceway openings should be low enough so that their highest point will be about the line at which it is desired to maintain the water level in the district. Their interior surfaces should be smooth in order to reduce friction which retards flowing water.

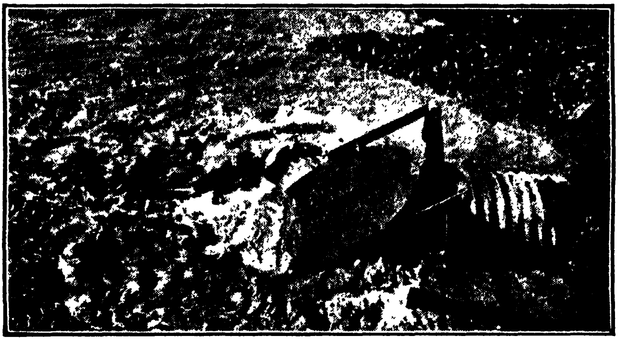

FIG. 110.—Automatic flood gate. (*Courtesy of Western Metal Manufacturing Company.*)

If the entrance to the pipes is made well rounded their maximum discharge capacity will be considerably increased. Automatic, outward opening flap valves may be put on the outer end of the pipes, but in important cases manual controls such as stop planks or gate valves should also be provided to stop the flow if the automatic valve should get out of order. On large sluices, hand operated gates of standard construction are much preferable to the automatic type, as they are positive in action and not likely to get out of order.

224. Pumping Plants.—The size of the pumping plant, its design, location, and construction should be entrusted to an experienced engineer. It is not possible in the space allowed here to go into the details necessary to treat this subject properly. Woodward has this to say about the size of the plant:

The size of the pumping plant required for any particular district depends upon a variety of conditions, among which are the size and slope of the drainage district and of any other area from which drainage water is received; the amount of storage capacity available in ditches and reservoirs; the system of interior drains used, and the method of construction adopted for the levee; the nature of the soil and sub-soil, the method of operation or operating policy of the pumping plant; the kind of crops raised and the degree of drainage required; and the amount and distribution of the rainfall throughout the year.

The majority of these plants are designed to take care of about ¼ inch of water over the entire area of leveed land in 24 hours. Recent studies indicate, however, that this should be increased to 3/10 inch for plants located in the upper Mississippi Valley and to from ½ to 1 inch for plants farther south. The plants, as a general rule, are operated from 60 to 90 (24-hour) days per year. They are run by electricity, gas, or steam power. The type of pump used is centrifugal, due to the fact that a large capacity is needed and the lift is low. Of late years, the screw pump, or a pump combining the screw and centrifugal principles, driven by a Diesel or semi-Diesel oil engine, has been gaining in popularity.

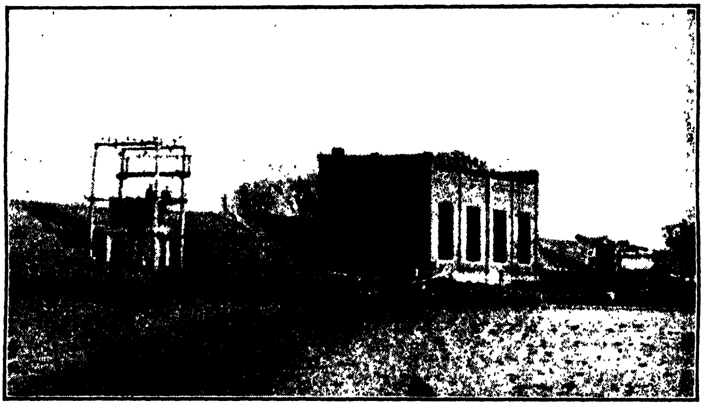

Fig. 111.—A modern drainage pumping plant operated by electricity.

The size of pump required, or the diameter of its discharge opening, can be roughly computed by assuming that the water travels through it at the rate of 10 feet per second. Pumps of this type are known by the size of their discharge openings expressed in inches. Thus, 15, 20, or 30-inch pumps have discharge openings of 15, 20, and 30 inches, (diameter) respectively.

CHAPTER XVII

DRAINAGE DISTRICTS

225. Purpose of Drainage Districts.—Drainage districts are formed by landowners in a given area, in accordance with the drainage laws of the state, for the purpose of constructing and maintaining drainage outlets of sufficient capacity to permit the satisfactory removal of excess surface and subsurface water from the area.

Such districts are formed primarily for the drainage of agricultural lands. Other lands, such as mining lands or factory sites, may be and often are included in drainage districts, however, and, in addition, an outlet is often provided for sanitary purposes.

226. Fundamental Principles of Drainage Districts.—Drainage districts come into being, first, at the option of interested landholders and, second, through operation of the law, which enforces the cooperation of the owners of benefited lands.

Most of the states having an important acreage of land needing drainage now have drainage laws providing specifically for the formation of drainage districts. Since drainage districts in their final form, therefore, are entirely creatures of the law, it is highly essential that they comply with the law in every detail. When properly organized according to law, drainage districts, in general, possess the following distinguishing characteristics:

1. They are a form of corporation and are empowered to act accordingly.
2. They are financially responsible, may sue and be sued, may borrow money and issue bonds in the district name, and may hold and convey property.
3. They are empowered to condemn property needed in carrying out the purposes of the district.
4. They are empowered to construct such improvements as are necessary to accomplish the reclamation of the lands in the district.
5. They are empowered to make an equitable distribution of all expenses among the landholders in proportion to the benefits derived and to levy taxes against each piece of land in the district to the extent of the benefits conferred and to enforce the collection of such taxes.

These are, perhaps, the most important basic features of drainage districts, all of which are provided for by law. There are numerous minor features, all of which are elaborations of these major features and which are covered in detail in the drainage laws of the different states.

227. Procedure in Forming a Drainage District.—A drainage district has its origin in the preparation of a *petition* signed by the requisite number of owners of land in the county abutting on the proposed improvement. The laws of the different states vary as to the necessary number of signers to the petition. Some require the signature of the majority of the landholders, while others require the signatures of the owners of a majority of acres. One state requires the signatures of three landholders, and several require the signature of only one. Mississippi requires that 10 per cent of the landholders sign the petition. The petition is then presented to the proper county official or board of officials designated by law, who may be the county auditor, the court, the board of supervisors, or some other official or board.

The petition must contain the name of the district, must state that certain lands are subject to overflow or are too wet for cultivation, and must set forth in general terms the boundaries and acreage of the district and give the names and addresses of the landowners, together with a description of the proposed improvement and a statement of approximate starting points, routes, and termini. A statement that the project is feasible and for the promotion of the public welfare is also usually required.

These particular points are generally required by all state drainage laws, but it is especially important that the petition contain all the facts and statements required by the state in question. Usually, the petition should close with the request that an engineer or board of viewers be appointed to make a preliminary survey to ascertain the desirability and practicability of the proposed drainage and what lands will be specifically benefited.

Usually, the petition must be accompanied by a bond for an amount sufficient to pay for preliminary survey and organization expenses, in case the district is not finally formed. In some states, other provisions are made by law to cover such expense, as holding the petitioners personally liable or authorizing the levy of a uniform tax not exceeding a certain amount on each acre of land in the proposed district. An engineer or board of viewers is then appointed, to proceed with the preliminary survey.

228. The Preliminary Report.—The report of the engineer or board of viewers must be submitted to the proper officials within a specified time. This report will give a general recommendation in addition to preliminary information regarding the location, character, and approximate cost of the project. It is merely advisory in nature, to aid in the decision as to the establishing of the district. No final or conclusive data are given.

229. The Hearing.—After the preliminary report is filed, all interested landholders are notified either personally or by publication of the pending petition and report and are called upon to appear at a designated time and place to present their views for or against the establishment of the drainage district. The purpose of this hearing is to give each owner an opportunity to protect his property against any unjust lien or tax. In some states, claims for damages which it is thought will result from the proposed improvements may be filed previous to and settled at the hearing.

230. Establishment of District.—Following the hearing, the court may order the establishment of the drainage district. Thereafter, the district is presumed to exist as long as any act pertaining thereto remains to be done. Each district is administered by a board of officers usually known as *commissioners* or *supervisors.* In some states, the county board of supervisors acts, but generally the commissioners are elected by the interested landowners from their own number. Where the state laws require county officials to act as drainage officials, the property owners have no choice in their selection other than through the general election of county officials. Where the laws permit the landowners to select the drainage officials, the board of drainage commissioners usually consists of from three to five resident landholders who select board officers from among themselves, including a chairman, secretary, and treasurer, except in states in which the law requires that the county treasurer shall act as treasurer of drainage districts. An adequate bond is required of the treasurer. The duties of the drainage district commissioners are, in general, to administer the district in accordance with the laws of the state.

The board of commissioners also selects and employs a competent engineer to supervise all the engineering work of the district. A competent engineer is likewise selected to supervise the construction of all improvements. Usually, both engineering and construction are supervised by one engineer, however, who is also placed under adequate bond. The judgment of the construction engineer should be final on matters relating to the interpretation of specifications and the acceptance or rejection of completed work. He is the expert medium between the commissioners and the contractor and should possess full authority as such.

An important specific duty of the drainage commissioners is to award the contract for the construction work of the district. In practically all states, the law requires advertising for bids before awarding the contract. To do this properly and effectively, the advertisement should be inserted in one or more engineering and construction journals, thus bringing the work to the attention of reputable and competent contracting concerns. It is always advisable to advertise for bids whether the law requires it or not, always indicating a time and place when all bids received will be opened and reserving the right to reject any or all bids. In many states, it is required in this connection to award the contract, if awarded at all, to the lowest competent bidder. This gives the commissioners a wider latitude in deciding on the low bidders but obviously calls for experienced and unbiased judgment. Quite naturally, the successful bidder is placed under bond, and the matter of establishing a valid and effective contract between the contractor and the district should be handled in accordance with competent legal advice. It is important that the engineer be present at the letting of the contract, ready to advise on all engineering features of the matter, in order that the contractors may bid intelligently and their bids be intelligently considered by the commissioners.

231. Estimation of Benefits.—After the engineer has completed his final report, plans, and specifications, and they have been approved by the commissioners, and the contract is let, and construction work underway, it is necessary immediately to estimate and report on the benefits which each tract of land will receive from the proposed improvements and apportion the cost of the work. In some states, a board of assessors is appointed by the court for this purpose. In other states, two disinterested landowners of the county are appointed as referees to act with the engineer in determining and estimating the benefits. This is a quite common method and has proved very satisfactory in many states. In some states, the estimation of benefits is made by the district commissioners themselves.

It is to be noted that, in most states, property in a drainage district cannot be taxed by special assessment in an amount

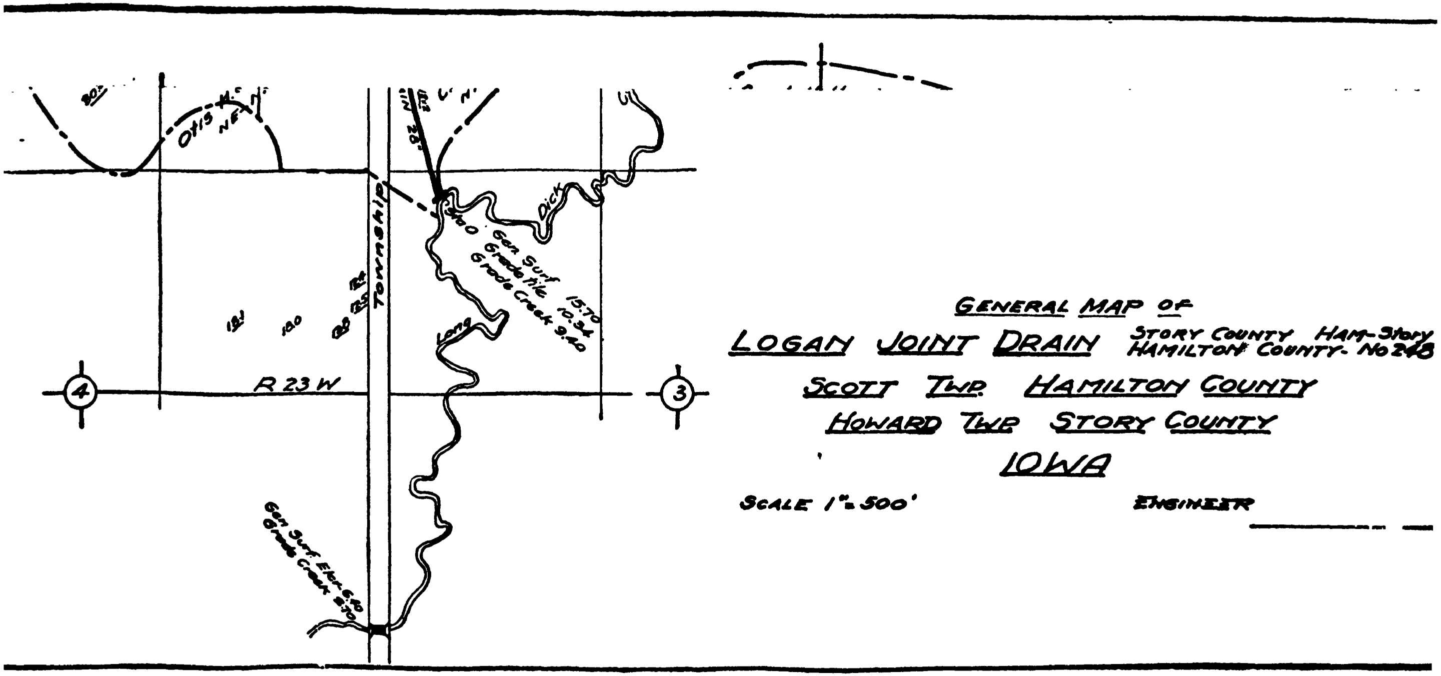

Fig. 112.—Map of a typical tile outlet project organized under the state drainage law of Iowa.

exceeding the benefits. The benefits on a cash basis may total an amount greater than the total cost of the improvements and usually do, but it is important that the board of assessors first consider benefits only and that they make certain of estimating the full amount.

232. Records of Estimates.—The benefits, as estimated, form the basis upon which each landowner is taxed for his share of the costs of the drainage district. These estimates must, therefore, be valid beyond question, and an accurate record should be maintained of the reasons forming the basis for the estimate on each tract of land. Many of the states require that each 40-acre tract or other subdivision of land according to ownership shall be considered in estimating the benefits. A plat of the district laid out in subdivisions of 40 acres is convenient to prepare and convenient to use in the field in estimating benefits. Notations of the decision of the board of assessors on each 40-acre tract can be made directly on the plat where it will be conveniently associated with other survey-engineering data. It is advisable, however, to keep a separate note record of detailed reasons for making each estimate.

233. Basis for Estimate of Benefits.—Since the assessment of taxes must be based upon benefits, it is advisable to discuss in detail some of the more important factors to be considered in making estimates. Each benefit estimated must usually relate to the betterment of the land for a purpose to which it may reasonably be put.

234. Elevation and Classification of Land.—The final basis to which all benefit estimates will directly or indirectly be referred relates to the elevation of the land with reference to the drain and to the distance of the land from the drain. With this in view, the board of assessors should not attempt to estimate benefits without having at hand a complete record of all rises and depressions of the different tracts and sufficient data on elevations of the adjoining slopes to indicate the lands possessing natural drainage. These data should be and usually are contained in the plat of the district.

With this information readily available, the assessors should personally inspect each tract of land in the district, viewing all parts of it carefully and noting all information pertinent to its classification and the determination of the benefit that it will receive. Lands are usually classed as swampy, wet, low, and well drained, or dry, these grades indicating their relative agricultural values. This point will be better understood by saying that swamp lands are lands which in their present condition are considered to have no agricultural value, while dry lands are those which have sufficient elevation and soils of the proper physical characteristics to permit adequate self-drainage and the unhindered pursuit of agricultural practices at all times.

This natural state of the land will have an important bearing on the amount of benefits estimated, since benefits must always be measured largely by the cost of reclaiming the land and by the consequent increase in its agricultural value. The value of dry lands in their natural state is usually greater than that of wet or swampy lands. The benefits of drainage are less, therefore, for dry than for wet and swampy lands, and for this reason the latter, requiring the greatest expenditure for reclamation, receive the greatest proportion of benefits and should be assessed accordingly. The classification of land is probably the most important single factor influencing the equitable determination of benefits, but there are also other factors of importance which should always be considered in connection with the classification in estimating benefits.

235. Proximity to Main Drain.—The proximity of the land to the main drain will greatly influence the amount of benefit received. It is evident that land through which the main drain passes, thus giving it the advantage of direct drainage into the outlet, should be assessed more than land of similar classification situated so that additional expense is required for the construction of collecting submains in order to realize the maximum benefit from the main outlet. In addition, the location of the main drain within a tract has a bearing on the benefits received, since, if it passes through the hilly parts of the tract, the benefits received will not be so great as if it passed through low or swampy parts.

236. Distance to Natural Outlet.—The location of the land with reference to the point at which the main drain empties into the natural outlet is often considered to have an important bearing on the benefits received. It is considered by some that land located close to the natural outlet should not, as a rule, be assessed so much as land located at the upper end of the main drain, on the basis that land located above is dependent upon the land below for an outlet and should, therefore, be assessed for main-drain capacity throughout the length of the drain. Perhaps the majority, however, are of the opinion that all lands similarly located and classified are equally concerned, since the capacity of the main drain must usually be gradually increased toward the outlet in order to take care of the waters from above in addition to the drainage from the adjacent lands.

There are exceptions to both views, however, particularly in the case of lands lying in subsidiary watersheds of sufficient elevation to keep their overflow waters from lands lying above, and which may or may not receive direct benefit from the main drain. The basis for the estimation of benefits for such lands is usually a proper proportion of the cost of the main drain from the outlet up to the point where it drains the subsidiary watershed.

237. Thoroughness of Drainage.—Consideration should always be given to the thoroughness with which each tract of land will be drained by the improvements. It is in this connection that the importance of an engineer member of the board of viewers is evident, especially if he be competent to design drains and to estimate the results which can be expected to be accomplished by a drain. In any event, the designing engineer should be freely consulted, as it sometimes happens that through error or through expediency the improvements will be so designed that a certain tract of land will not be thoroughly drained, owing, perhaps, to its location. It may be that the expense of the improvements would be unduly increased if it were designed to drain thoroughly a particular tract. In such a case, it is often better partially to drain the tract with the more economical design and adjust the assessment accordingly. Needless to say, such land should not be assessed so highly as land receiving the benefit of more thorough drainage.

238. Soil Fertility.—The relative fertility of the soils of the different tracts of land in a drainage district is one of the important bases for the estimation of benefits. Its determination, however, is rather difficult, unless there are marked differences in the general nature of the soils of two tracts. The difference in fertility between sandy, rocky, or badly eroded soils and level, productive loam soils is marked and should be considered in making assessments. But in some of the typical agricultural localities, the soils are generally so uniformly fertile that it is not considered practicable to make allowances for differences in fertility. Furthermore, if difference in fertility of soils is considered, a distinction should always be drawn between permanent and temporary infertility of soils. Sandy or rocky soils are usually more or less permanently unproductive, while normally productive soils may be rendered temporarily unproductive through alkali resulting from improper use of irrigation water and inadequate drainage or other causes. In short, land which is permanently fertile and yields large crops should be assessed more than permanently infertile land or that which is at least temporarily infertile and yields only small crops. If practicable, the temporarily infertile land should also be assessed more than the permanently infertile land, always, of course, considering the probable cost of improving the former. Since the question of soil fertility requires judgment and advice of an expert nature similar to that obtained from the engineer, it is well for the board of assessors, where such questions arise, freely to consult the department of soils of the state agricultural college or experiment station.

239. Variations in Prevailing Grade.—In most drainage districts, there will be found a variation in the prevailing rate of fall of the watershed in different portions. Naturally, the greater the fall available the less expensive should be the drainage system designed and the less such lands should be assessed.

There may be other similar physical advantages possessed by certain portions of a district over other portions, which will have a bearing on the estimation of benefits and the apportionment of costs, although, in general, it will be found that those discussed above are the most important. Broad vision and experienced judgment are required in all cases in order to do absolute justice to all landowners. Extreme care and careful study are required on the part of the assessors, and they should take advantage of any and all expert advice and information available which will place the estimates on a firm and unassailable basis. The importance of this will be appreciated when it is remarked that more dissatisfaction and litigation have resulted from improperly made benefit determinations than from any other one factor connected with drainage districts.

240. Assessment of Lands in Accordance with Benefits Received.—From the above discussion, it is evident that a number of variable factors enter into the estimation of benefits to the different tracts of land in a drainage district, thus making it difficult if not almost impossible to state what proportion of the total expense shall be borne by each tract without the adoption of some method or system of comparative apportionment of the expense on the basis of the benefits derived. There are a number of methods of doing this, some of which will be briefly outlined.

241. Arbitrary Assessment.—In small districts where there is not a great amount of variation in the general characteristics of the different tracts of land, an arbitrary assessment of cost is sometimes made in the field. In other words, a certain part of the total cost of the district is apportioned to each tract of land, using the average cost per acre as a working basis. If the first assessment does not cover expenses, the land is subject to a second assessment, and so on. This method has been fairly successful in small districts under the operation of well-informed assessors but is obviously not adapted to the large districts where the conditions are much more variable.

242. Uniform Cost per Acre and ad Valorem Assessments.—In districts where the benefits derived by the different tracts of land are more or less uniform, as in the case of levee work, it is sometimes the practice to divide the total cost of the district equally among the total acres, making a uniform cost per acre. This is, of course, a very convenient method, but it depends for its fairness upon uniformity of benefits received by the different tracts, which is, after all, a rather rare occurrence. Again, in such districts, the distribution of costs is often made in proportion to the value of the abutting land, on the assumption that the district is a public improvement. This method is, however, usually limited to levee work.

243. Assessment on Basis of Increased Land Values.—The distribution of the expenses of a district may be made on the basis of the increased value of the land in each tract as a result of the improvements or, more specifically, on the difference in value of each tract of land before and after the improvements are constructed. The successful use of such a method obviously calls for the highest grade of expert judgment on the part of the assessors in order to make equitable and uniform determinations of increases in land values. In computing the cost per dollar of increased value for each tract of land, the total cost of the district is divided by the total estimated increase in value of all the lands of the district. The total assessment to each tract is then found by multiplying the per-dollar benefit cost by the total dollars of benefit.

244. Assessment by Classification.—A rather inelastic method of distributing the costs of a district, but one that does not throw so much weight upon the judgment of the assessors, is the placing of the lands of the district in a certain number of classes defined and prescribed by law. It is the duty of referees or assessors to determine into which class each tract of land will fall. According to the cost of the district, the lands in each class are assessed a certain amount per acre. While this method may reduce the total amount of work required, it is obviously lacking in elasticity and may frequently do injustice, particularly in states where the number of classes prescribed by law is small and the method is applied to a district with lands of widely varying nature.

245. Assessment on Basis of 100.—A method often used for the distribution of district expense is the comparison of tracts of equal size on the basis of 100. The district is divided up into tracts of equal size, frequently 40 acres, and the referees classify each tract, those receiving the maximum benefits being classed as 100, and the other tracts being classed less in accordance with the relative amount of benefit received. Needless to say, the same care and expert judgment are required to give equitable and uniform classifications as in the method where distribution in cost is determined by the increase in value of the land due to the improvement. This method, however, has been used with considerable success and satisfaction to the landholders. The classification number indicates not only the relative amount of benefits received but also the actual number of units of benefit received. The cost of each unit of benefit is determined by dividing the total net cost of the district to the land by the total number of benefits to the land, and the total cost to each 40-acre tract is obtained by multiplying by the cost of a benefit unit the number of benefits to the tract. In using this method, the apparent difficulty arises that landowners will not always own a number of acres which is a multiple of the size of tract selected for classification. This should be considered somewhat in selecting the size of tract. Then, if 40 acres is the base size of tract, and a certain 40-acre tract, which is given a classification of 60 or receives 60 units of benefit, is owned one-half by one man, one-quarter by a second, and one-quarter by a third, the man owning half of the tract must pay for half or 30 of the benefit units, and each of the other two must pay for one-fourth or 15 of the benefit units. The assessment roll will indicate all this information by columnar development. An example of an assessment roll made up on a basis of 100 is shown below.

Assessment Sheet for Drainage District No. 1 on 100 Basis

Owner's description of land	Number of acres		Number of benefit units	Assessment
A	160	40	80	$ 257.11
		40	50	160.70
		40	100	321.39
		40	60	192.84
B	120	40	10	32.14
		40	35	112.49
		40	40	128.56
C	80	40	100	321.39
		40	100	321.39
D	20	40	...	144.62
E	20		90	144.62
F	15	40	...	120.52
G	25		100	200.87
H	80	40	90	289.25
		40	80	257.11
Total	520		935	$3,005.00

Cost of drainage improvements		$3,000.00
Damages awarded		300.00
Highways	$120.00	$3,300.00
Railroads	175.00	295.00
		$3,005.00

$\frac{3,005}{935}$ = $3.2139, the cost of 1 benefit unit.

246. Assessment on Percentage Basis.—A refinement of the 100-basis method is the percentage of benefit method which reduces the assessment to an acre basis and provides for a more detailed consideration of all the factors described above, which constitutes the basis for estimating benefits received by each tract of land. Such a method is, perhaps, the fairest that can be used, and, since it gives ample opportunity for the exercise of expert judgment, is certainly the most scientific. Good judgment and expert knowledge are required from beginning to end in the use of this method of distributing the district's expenses. It is the first duty of the assessor to divide each farm into tracts such that the benefits received from drainage will be, as nearly as possible, uniform within a tract. In other words, each acre in a tract selected receives approximately the same benefit as any other acres in the same tract. With this in view, each tract is inspected in the field, and each one of the factors determining benefit from drainage is assigned a percentage. For instance, it may be assumed that each acre in a 50-acre tract is 60 per cent benefited with respect to nearness to outlet, 70 per cent with respect to fertility, 100 per cent with respect to elevation or thoroughness of drainage, and 60 per cent with respect to nearness to main drain. A 100 per cent benefit is, of course, the maximum benefit obtainable. These percentages of benefit determined from a detailed consideration of each influencing factor are then multiplied together, the product giving the total percentage of benefit per acre in the tract. In the case assumed, the total percentage benefit per acre would be $0.60 \times 0.70 \times 1.00 \times 0.60 = 25.2$ per cent, or, more conveniently expressed, 0.252. This percentage factor is multiplied by the total number of acres in the tract which gives the total number of acre units of benefit received by the tract. The sum of all of the acre units of benefit received by all the lands of the district, divided into the net cost of the district to the land gives the cost per acre unit of benefit. This cost multiplied by the number of acre units received by each tract gives the actual amount of the cost of the district which is assessed against the tract. An example of an assessment roll made up on the percentage basis is shown in the table on the following page.

It is to be noted that the methods which may be used for distributing the costs of drainage districts are usually prescribed by the drainage law of a state. This is not always the case, however, and where it is left to the discretion of the engineer, the drainage commissioners, or the board of assessors to decide on a method, it is always well to select one which is elastic and will give the assessors the widest possible latitude in the exercise of judgment and the employment of expert advice, in order that justice may be meted out to all in the highest degree.

It is always well for the assessors to have complete data available. Even if the law requires a distribution of benefits only on a percentage or some other basis, it is always advisable to have data available as to the actual amount of benefits received by each tract in dollars and cents and to include this in the report if it is deemed necessary.

Assessment Sheet for Drainage District No. 1 on Percentage Basis

Owner's description of land	Number of acres		Percentage benefit per acre	Acre units of benefit	Assessment
A	160	30	70	21	$166.28
		50	60	30	237.54
		20	100	20	158.36
		20	90	18	142.52
		40	70	28	221.70
B	120	40	10	4	31.67
		50	45	22.5	178.16
		30	30	9	71.26
C	80	40	100	40	316.70
		40	100	40	316.70
D	20	20	90	18	142.52
E	20	20	90	18	142.52
F	15	15	100	15	118.77
G	25	25	100	25	197.95
H	80	30	70	21	166.28
		50	100	50	395.90
Total	520		...	379.5	$3,005.00

Cost of drainage improvements		$3,000.00
Damages awarded		300.00
		$3,300.00
Highways	$120.00	
Railroads	175.00	295.00
Total net cost to land holders		$3,005.00

$$\frac{3{,}005.00}{379.5} = \$7.918, \text{ cost per acre unit of benefit.}$$

247. Benefits to Railroads, Highways, Town Lots, Etc.—It is usually required that the benefits received by railroads, highways, rights-of-way, town lots, and other property shall be considered and estimated and that they shall be assessed a certain part of the cost of the district. That part of the cost of the district to be paid by the owners of such property is usually assessed in a lump sum and is usually a percentage of the total cost of the district based on the actual amount of benefit received.

In estimating the assessable benefits to railroads and highways, only those benefits of a determinate character are to be considered, such, for instance, as the decrease in cost of maintenance due to drainage. Such apparent benefits as increase in traffic and freight revenues due to improved railroads or highways are more or less speculative and should, as a rule, be given little weight.

The assessable benefits to railroads and highways are mainly those received by roadbeds, which render them more solid, less liable to injury from washouts, settling, and frost action, those which reduce the number of bridges and culverts required, and those which make maintenance, in general, including fences and telegraph poles, less difficult and expensive.

Town lots can usually best be assessed by distributing that part of the total cost apportioned to them according to area, elevation, and location of the different lots.

It is to be noted that the lump sum which is assessed against railroads, highways, town lots, and rights-of-way should be deducted from the total cost of the district before the cost is distributed among the different tracts of land in the district according to the benefits derived.

248. Appraisal of Damages.—Most state drainage laws provide specifically for the awarding of damages to parties whose property is injured by the construction of a drainage district. Such property owners are usually subject to tax on account of benefits, but damages and benefits are two separate and distinct factors and, therefore, should be considered entirely separately. The damages as determined and awarded should be paid, and the amount added to the total cost of the district. The benefit assessors may appraise such claims, or a special claims board may be appointed. Usually, the state law covers this point.

249. Damages to Land.—Damage claims assume their greatest importance when the main drain is an open ditch. The primary claim for damages in such cases is, of course, for the land in the right-of-way as condemned by the district for open-ditch construction. The-right-of-way will include a land area of sufficient width to provide for the ditch, the berm, and the waste banks. It is important in awarding damages for right-of-way that every factor of importance be considered to prevent future litigation. For instance, it is frequently the case that the main ditch is cut by a dipper dredge through land which is of slightly greater elevation than the surrounding land. Again, the right-of-way and the surrounding land may be of uniform elevation, but the elevation of the waste banks may normally be much higher than the surrounding land. Frequently, in such cases, the dipper dredge will back up to clean out the bottom of the ditch and will deposit on top of the waste banks a great mass of oozy material which will flow more or less easily over the surrounding land. This often produces a condition of temporary infertility, which takes considerable time and expense to rectify.

As to the actual value of the land on the right-of-way, there has been considerable discussion. Many consider the award of damages for this land in the light of a sale of the land on the basis of its value before draining. This, however, takes away from the landowner his possible legal right to benefit by the proposed improvement. It would, therefore, seem more just to award as damages the probable value of the land in a drained condition. This method, too, is open to some question, since it would be necessary to assume that the land would receive 100 per cent all-round benefit. This might not be true if the ditch were given another location, since relative elevations and horizontal distance might be entirely changed. It can thus be seen that the laying down of any hard-and-fast rule for the awarding of right-of-way damages is inadvisable. On the other hand, such awards should evidently be made on the basis of a thorough consideration of every possible influencing factor, giving the landowner ample opportunity to air his side of the question. Once the landowner is satisfied, his release should be obtained from any further similar claims.

In some states, the basis for the award of right-of-way damages is prescribed by law. In some states, also, it is not necessary for the landowner to claim right-of-way damages, these being awarded automatically as part of the regular procedure in executing the work of a drainage district. Experience usually indicates, however, what is the most convenient, equitable, and inexpensive procedure.

There are, also, the usual claims for damages because of the inconvenience in farming operations and general reduction in value of a farm through which a ditch is constructed. The cost of bridges over a ditch for convenience in farming operations and the cost of fences on both sides of the ditch to prevent the access of stock are also equitable bases for damage claims. Sometimes, the ditch will isolate small, irregularly shaped tracts of land in a farm the agricultural value of which will not justify the construction of bridges and fences. The total value of such land is an equitable basis for a damage claim under such circumstances. The matter of the future maintenance of bridges and fences should be settled at the time the damage claim is settled, to prevent future litigation.

Some state drainage laws require that the injured landowner shall make claim for damages within a specified time. This would be theoretically just if it were possible to foresee and estimate all damages that might arise. But, practically, it would seem more just to the landowners to give the claims board a wider latitude in receiving and adjusting claims as reasons for them occur, when it is considered that many unforseen and more or less unpreventable accidents may occur during construction which cause great damage to adjacent lands. An instance of this occurred when a ditch was being dug by floating-dipper dredge and a service dam was broken by an unusual flood, causing great injury to adjacent lands and property. Another instance occurred when a certain county elected to construct a service dam over the old waterway to serve also as a new roadway; a small freshet ensued which, instead of attacking the dam, chose to follow the line of the new channel and, after reaching the end of the ditch as dug, zigzagged in three directions over a fertile 40-acre tract, cutting ragged irregular ditches, 10 to 12 feet deep, to the old waterway below and ruining the tract almost beyond redemption. While such accidents may be relatively infrequent, it would seem more just and more conducive to the satisfactory prosecution of the affairs of drainage districts to provide for them.

250. Damage to Highways and Railroads.—Highways have just claims for damages in the removal or the building or rebuilding of any bridge or bridges, made necessary by a change in a watercourse, or in the building of a ditch crossing the highway. In some states, such expense is borne by the county road fund, but more frequently it is considered a just basis for damages due the township road fund. Other bases for damage claims by highways are the cost of inconveniences to the traveling public incident to the construction of the drain across the highway and the moving and rebuilding of bridges.

Damages awarded to railroads are usually for the cost of the materials and labor for the construction of the ditch or drain across the railroad right-of-way. The cost of new bridges, owing to a change in the water course, or of the reconstruction of old bridges to take care of an increased volume of floodwater, is not considered a just basis for a claim for damages. The state drainage laws usually outline quite specifically what damages may be claimed by railroads.

It is to be noted that the matter of appraisal of damages is one requiring as much good judgment and expert knowledge as the estimation of benefits. Hence, the importance of an engineer member on the damage-claims board. Where the board does not include an engineer, advantage should always be taken of the expert advice and assistance of an engineer, who is conversant with such matters, especially in case of doubt as to proper procedure.

251. Estimating the Cost of Drainage Districts.—Before the cost of a drainage district can be distributed among the different property holders benefited, an estimate of the cost must be prepared. The items making up the total expense of a drainage district are normally as follows: (1) cost of constructing the improvements, which, in many cases, is done by contract at a price per cubic yard of excavation to cover all costs of construction; (2) engineering expenses, which are usually incurred on a contract basis; (3) expenses due to claims for damages, as discussed above; (4) legal expenses, which are usually incurred by the employment of an attorney to handle all the legal affairs of the district; (5) fees of commissioners, assessors, and other district officials usually prescribed by law.

252. The Assessment Roll.—After all the necessary field examinations have been completed, benefits estimated, damages appraised, total net expense computed and distributed, an assessment roll is compiled. This roll should give the name of the owner of each piece of property assessed; a description of the property, including its location, the number of acres, the amount of benefits estimated, shown either as a number of benefit units, benefits in dollars and cents, or both; the amount of property taken for right-of-way, and its value, and any damages awarded. It is to be noted that, even if the law requires that benefits be indicated only on a percentage or other basis, it is always advisable, if possible, to indicate the benefits to each tract in dollars and cents.

Upon completion of the assessment roll, it is filed with the court and notice is given to all interested persons and landowners in order that they may appear at a definite time and place and object to the assessments against their land if they so desire. This notice should contain a description of the lands assessed, the amount of the assessment in dollars and cents, and the name of the landowner, especially if the notice is given by publication only. At this hearing, objections to damages awarded may also be heard and adjusted.

It should be noted that accuracy in the preparation and serving of the notice of the filing of the assessment roll is of the utmost importance, for upon the assessment roll as finally approved by the court at this time rests the enforceability of the collection of taxes against each tract of land. The description given in the notice should, therefore, be carefully checked against those in the engineer's report.

At the hearing, the court approves the assessment roll, after making such changes as are deemed necessary in order to do justice to all. After approval of the roll by the court, the district commissioners cannot make any changes therein without first giving notice to all landowners.

Each landowner has the right to appeal to a higher court within a certain time, from the decisions of the court as to benefits and damages. This rule holds in most states, but unless the appeal is made within the time limit specified, his right to appeal is lost.

The assessment roll in finally approved shape is filed with the county recorder.

253. Levy of Drainage Tax.—After approval of the assessment roll, the court orders a tax levy against the properties in the drainage district equal to the estimated cost of the improvement as distributed according to the benefits received and usually plus 10 per cent, added for unforeseen contingencies. While the drainage laws of a number of the states provide specifically for this 10 per cent extra levy for contingencies, it is usually considered advisable to add it to the tax in any event, since, almost inevitably, additional and unforeseen costs arise as the work of construction progresses.

254. Financing of Drainage Districts.—There are several methods of financing drainage districts, such as issuing certificates of script, permitting each landowner to pay his share of the cost in advance of construction, or issuing bonds; but the method of issuing bonds is, perhaps, the most generally practiced, especially in the larger districts. The other two methods mentioned have such obvious disadvantages, except under certain ideal conditions, that they will not be discussed here.

A certain time limit, usually at least 30 days, is allowed within which drainage taxes can be paid in one amount. After this time has expired, in order to obtain cash to carry on the construction work, it is necessary for the district commissioners to issue and sell the bonds of the district, amounting to the difference between the total tax levy and the amount previously paid in cash.

It is to be noted that funds must always be available during construction, as the contractor is usually paid monthly for the work done as determined by the construction engineer, minus 10 to 20 per cent.

Drainage bonds are now usually of the serial type, so that a certain number fall due each year. Until the bonds are paid, they draw interest; hence, the necessity for the landowners to pay interest on unpaid taxes.

It is generally agreed that the length of time over which drainage bonds should extend should be determined largely by the life of a drainage improvement. This will vary more or less widely with conditions, but the general custom is to have the last series of bonds mature not later than the twentieth year, and, in many cases, the bonds are all paid within from 10 to 12 years.

In some states, recently enacted laws provide that the amount of bonds which may be sold is limited to 90 per cent of the total amount of the taxes levied. This limitation adds to the selling value of the bonds and appears to be advisable, since, by thus collecting more taxes than are necessary to pay the maturing bonds, there will always be enough money on hand for the prompt payment of bonds and interest, especially in case of default by a taxpayer.

By this method, as the years go by, the funds will increase, and when the last installment of taxes is due, it can be adjusted in accordance with the surplus on hand.

It is to be noted that the law makes the drainage tax a lien on each tract of land which is assessed, so that the landowner who pays his tax promptly does not pay for the landowner who is not prompt in his payments.

Most state laws prohibit the sale of drainage bonds bearing more than 6 per cent interest, and in this connection it is well for drainage commissioners to consult reputable bonding houses.

It is to be noted that, in matters relating to the finances of drainage districts, it is of the utmost importance that the drainage commissioners be familiar with and comply strictly with the state drainage laws. Needless to say, competent legal assistance should always be available and constantly consulted in order to prevent trouble and litigation.

The commissioners alone are responsible for the proper use of all funds. The importance, therefore, of complete and accurate records cannot be overemphasized.

CONSERVATION DISTRICTS

It is now apparent that the basic features of drainage district laws are: (1) benefits must equal or exceed the cost and (2) costs must be distributed among the various landholdings in direct proportion to benefit derived. These principles are not so applicable to lands subject to erosion where inaction results in large capital losses to the immediate owner and in probable damage to his neighbors and to the public.

In 1937, the federal Soil Conservation Service prepared legislation for proposed conservation districts to correct this situation. Twenty or more states are reported to have enacted this legislation within a year after its proposal, with only minor modifications. Basic provisions of these acts are as follows:

255. What the Standard Act Provides.—The standard act provides procedure whereby farmers may voluntarily join together and organize themselves into a district so that they may apply on their lands the practices learned from state and federal erosion-control demonstration projects. Such voluntarily organized districts are to be governmental subdivisions of the state and may exercise two types of power:

1. The power to establish and administer erosion-control projects and preventive measures;
2. The power to prescribe land-use regulations in the interest of the prevention and control of erosion, such regulations to be first submitted to local referendum and, if approved in the referendum, to have the force of law within the district.

256. The State Committee.—The act establishes a "State Soil Conservation Committee," which has power to define the boundaries of each district, to encourage the organization of districts, to bring about an exchange of information and experience among the districts in the state, and to coordinate the several district programs so far as this may be done by advice and consultation. Each district is an independent unit and is not subject to the control of the state committee. The act provides that the state committee shall have not less than three nor more than five members, and that the following shall be its members: The state director of agricultural extension and a member of the State Planning Board. The committee is authorized to invite the Secretary of Agriculture of the United States to appoint one person to serve as a member of the committee. The remaining two or three members, as the case may be, are to be appointed by the governor and confirmed by the state senate.

257. How Districts Are Organized.—The procedure of organizing districts is as follows: Any *twenty-five* land occupiers may petition the state committee to establish a district. *The act defines "land occupier" to include any person or corporation who holds title to or is in possession of lands, either as owner, lessee, renter, tenant, or otherwise.* The committee is required to hold a public hearing on the petition (within 30 days), to define the boundaries of the proposed district, and then to submit the question whether the district should be created to all occupiers of lands lying within the boundaries defined. No district may be established unless a majority of the votes cast in the referendum are in favor of such creation.

258. The District Commissioners.—Each district is to be governed by a board of five commissioners, two of whom are to be appointed by the committee, and three are to be elected by the qualified electors of the district. The three candidates who shall receive the largest number, respectively, of the votes cast in such election shall be the elected commissioners for such district. Each commissioner, whether elected or appointed, holds office for 3 years, except the two first appointed, who shall be designated to serve for terms of 1 and 2 years respectively. The commissioners are to receive no compensation other than expenses necessarily incurred. The commissioners may employ a secretary, technical experts, and such other officers as they may require. The three elected commissioners form the governing body of the district, *i.e.*, have voting power.

259. What the Districts May Do.—When organized, each district will have power to do research in erosion control; to conduct demonstrational projects; to carry out preventive and control measures; to enter into contracts with farmers and give them financial and other assistance; to buy lands for retirement or for project purposes; to make loans and gifts of equipment, machinery, seeds, etc., to farmers; to take over and operate state and federal erosion-control projects; and to recommend land-use plans for soil conservation. These powers can be carried out upon private lands only with the consent of the owner.

In order to avoid duplication, any research work undertaken must be in cooperation with the state agricultural experiment station and pursuant to a cooperative agreement between the experiment station and the district; and, likewise to avoid duplication, extension activities on demonstrational projects are to be carried on in cooperation with the agricultural extension service and pursuant to a cooperative agreement entered into between the extension service and such district.

260. Land-use Regulations Binding on All Lands.—In addition to the powers listed above, the commissioners of each district may formulate an ordinance prescribing land-use regulations for soil conservation. Such regulations cannot go into effect, however, until after they have been submitted to a referendum of the land occupiers and have been approved in such referendum by a majority of the votes cast. The regulations may be amended or repealed, but only after such amendment or repeal has again been submitted to a referendum. These regulations may include provisions specifying cropping programs and tillage practices, including rotations; requirement that steep or otherwise highly erosive land be retired from cultivation; requirements for particular methods of cultivation, such as contour cultivating, lister furrowing, strip cropping, planting of trees and grasses, etc.; and engineering operations, such as construction of terraces, check dams, etc.

261. How Regulations Are Enforced.—Failure by land occupiers to observe the regulations is punishable by fine as a misdemeanor. In addition, the commissioners may file petition with the local courts asking the court to order the land occupier to observe the regulations. Such court order may provide that if the land occupier fails to perform, the commissioners may go upon his lands, do the necessary work, and collect the costs from the land occupier.

262. Allowing Exceptions to the Regulations.—In any district which adopts land-use regulations, the act requires that a board of adjustment be established. Upon petition of the land occupier, the board of adjustment is authorized to permit variances from the land-use regulations in cases where application of the strict letter of the regulations would result in "great practical difficulties or unnecessary hardship." Decisions of the board of adjustment are subject to review in the local courts.

Districts are authorized to cooperate with one another, and all agencies of the state are directed to observe, on lands which they are administering, all applicable land-use regulations.

263. Discontinuance of Districts.—After a district has been in existence for 5 years, land occupiers may petition for discontinuance of the district. The question of discontinuance must be submitted to a referendum, after which the district will be dissolved unless a majority of the votes cast are in favor of continuance.

264. Sources of Funds for Districts.—Funds to finance the operations of the districts will come from these sources:

1. Direct appropriations out of the state treasury, to be divided among the districts by the state committee.
2. Grants-in-aid made, either directly to the districts or through the state committee, by the Soil Conservation Service or other federal agencies.

The districts are not authorized to levy any taxes or special assessments or to issue bonds.

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CHAPTER XVIII

USEFUL PRINCIPLES OF LAW

It is essential that each farmer should understand his rights according to law regarding the waters of the farm. Often unnecessary friction and lawsuits could be avoided if each one understood his rights in the matter. It is, therefore, fitting that a short time should be spent in the study of the law pertaining to this subject.

The following subject matter (**Arts. 265 to 279** was taken from Green's "Law for the American Farmer."[1]

265. What the Waters of the Farm Comprise.—The term *waters of the farm* is used in this chapter rather loosely and in a broad and general sense. Since an owner of a farm owns the bed of every sheet of water inside its lines and of every watercourse that runs between them and to the center of lakes and streams, not navigable, that bound it; the term employed embraces, primarily, all bodies of water great and small, from lakes and ponds to springs and wells, lying within the boundary lines of the farm, and all streams that flow across it from the point of entrance to the place of departure, and, as well, every arm or inlet of the sea, and fresh-water lake, and every river and creek, of which the shore or bank, the middle or thread, constitutes a farm boundary. But the term here means more; it includes also all surface waters due to rains and snows and all subsurface and percolating waters which feed the farm's wells, springs, and pools. And it includes, in addition, water congealed naturally into ice. Some of the waters mentioned belong to the farmer as absolutely as does the soil of the farm, and in all of them he has certain rights of use, enjoyment, and disposal either incidental to littoral or riparian proprietorship or to good husbandry in cultivating the farm. In respect of all these waters, the farmer has certain obligations and duties that he may not safely ignore if he would avoid injuring other people and incurring consequent liability for damages.

266. Bodies of Water.—Land under the sea and the great navigable lakes and rivers belong, in general, to the sovereign. The title to a tidewater bay, unless proved to be lodged elsewhere, is presumed to be in the state. That is called an *arm of the sea* where the tide flows and reflows, and only so far as the tide does ebb and flow. The area of a sheet of water does not determine the question whether it is a pond or a lake. If an unnavigable lake is of considerable size—for example, several miles long—and fourscore or more rods wide, a deed of land running to and along it will convey no part of its bed. The bed of a lake includes only the soil covered more or less permanently by water so as to be unfit for the growth of vegetation; it does not include border lowland useful for pastures or meadows although frequently flooded by rising water. For some purposes, a sheet of water may be a lake, notwithstanding it is too shallow for navigation of any sort; that marsh grass grows above its surface; that its bed is not always submerged; and that it is popularly known as a marsh.

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[1] GREEN, J. B., Law for the American Farmer, Chap. X, The Macmillan Co., 1923, reprinted by permission.

267. Watercourses.—A mere inlet from the sea filled and emptied more or less by the action of the tides is not a watercourse. A watercourse is a channel or canal for conveying water, particularly in the drainage of lands; it may be natural or artificial, but it must have a bed, a distinct channel, and defined banks traversing the soil. It is a stream of water running in a certain direction in a channel between well-defined banks. It is a living stream with definite banks, a channel, and a mouth distinguishable from its source, fed by something more permanent than mere surface water. Mere gullies of running water fed by occasional rains or melting snows are not watercourses. A watercourse, however, does not cease to be such by now and then running dry, or by spreading out in places into swamps and marshes, yet it does not mean a mere slough. The volume of water flowing in a stream does not affect its character as a watercourse; neither does the size of a stream determine whether or not it is a river. The channel of a stream is its bed, more especially the deeper part of the bed where the main current flows and, if navigable the line of deep water followed by vessels, where they may and usually do pass each other.

268. Navigable Streams.—Running streams are either public or private, and whether or not any particular stream is public or private depends upon whether or not it is navigable. If it is navigable, it is public, although its bed may be owned by private riparian owners. A navigable stream is a public highway and must not be obstructed, but the owner of both sides of a stream not navigable has a right to build and maintain a fence across it. The government alone has the right to establish a ferry across a navigable stream; it is not a matter of private right, although any private person may rightfully keep and use a boat for himself, his family, his servants, and even to carry a guest in crossing a public river without running a ferry or infringing on a ferry franchise. All streams which are channels for useful commerce are esteemed navigable and are classed as public highways; they are natural highways, and the public easement in them whatever its extent, is paramount to private riparian rights. The courts are not agreed upon what constitutes a stream a navigable one. At common law, streams were navigable no farther than tidewater extended. In New Jersey, the test of whether a stream is public or private is, Does the tide ebb and flow there? and not whether it is or is not navigable in fact. In North Carolina, streams are not considered navigable unless they can be navigated by seagoing vessels. On the other hand, the United States Supreme Court has said that any sort of vessel that can float upon water, whether driven by steam, wind, or muscular power, may be an instrument of commerce and transportation, and that if it is used for some useful purpose of trade, it makes the stream on which it plies navigable, and that rivers which are navigable in fact are public navigable rivers in law. Navigability in fact is enough in both Pennsylvania and Minnesota to make a stream a navigable one in law. The navigability of a stream depends upon its capacity to accommodate boats used for navigation and not upon the actual commerce carried on over its surface. A stream may be navigable although it is too shallow in places to allow the passage of boats over all parts of it, and it is navigable if it affords passage for boats and barges up and down at certain seasons of the year. It must, of course, contain enough water to fit it for transportation for at least a goodly part of the year; for if most of the time it is too shallow to accommodate any vessels except rowboats used for pleasure, and has never been actually navigated, it is not navigable. A river not navigable in its natural state cannot be converted into a navigable stream by artificial works destructive of riparian rights, without making compensation to the riparian proprietors. The repeal of a statute which declared a river a public highway does not operate to extend riparian titles to the middle of the stream. A natural watercourse, being a natural easement, is placed on the same basis, in many respects, as to the public right as is a public highway.

269. Floatable Streams.—A stream which is not large enough and deep enough to be navigable in the technical sense but which is of sufficient volume to float rafts or logs to market is termed a *floatable* stream. If a stream is almost or quite always deep enough and strong enough to float down logs, it is a public stream and classed as navigable. The rights of the public in a stream used to float logs are measured by its capacity in its normal state. That logs, poles, and rafts are floated down a stream occasionally when the water is high does not make it navigable. The natural flow of a stream cannot lawfully be held back in storage by upper proprietors and let loose in floods in order to carry down floating timber if thereby lower proprietors suffer damage; unless, indeed, the legislature by statute confers a right to build a storage dam and impound the waters and to open the dam from time to time to float logs downstream. The owner of logs floated carefully and prudently down a public stream is not liable for any consequential damages to lower riparian lands. If the logs are driven in a careful and prudent way, there is no liability; but the careless or reckless log driver is liable for damages caused by jams to shore lands. The right to float timber down a stream gives the log driver no right to use the banks in aid of his work; if he fastens booms to trees on the banks, he is a trespasser; he must not trespass on the banks to break jams and facilitate the drive. One who puts logs upon the ice of a stream and gives them no further attention renders himself liable for injuries caused to a lower landowner by the cutting of a new channel through his land in consequence of the formation of a dam by the logs and broken ice in the spring. A statute of Wisconsin gives log drivers a right to compensation for driving, of necessity, logs which get tangled with their own at the beginning of or along the drive.

270. What Is Meant by Riparian.—The word "riparian" is derived from the Latin word *ripa*, which means the shore of a river. Strictly speaking, when it is applied to a landowner, the word refers to the proprietor of the bank of an unnavigable stream. When the proprietorship of land bordering upon the shore of tidal waters is meant, the proper word is "littoral." In practice, however, little or no distinction is made. Land is riparian only when waters flow over it or along its border. The authorities generally limit the extent of riparian land to the watershed of the stream and hold that the upland beyond, although a part of a single tract under one ownership with the bank of the stream, cannot be deemed riparian; but in some states, this is not the rule. When land bordering on a navigable stream is permanently submerged or washed away, it is lost to the owner and can be regained only by accretion afterward.

271. Riparian Rights.—Water is the common and equal property of everyone through whose land it flows, and the right of each landowner to use and consume it without destroying or unreasonably impairing the rights of others is the same. An owner of land bordering on a running stream has a right to have its waters flow naturally, and none can lawfully divert them without his consent. Each riparian proprietor has an equal right with all others to have the stream flow in its natural way without substantial reduction in volume or deterioration in quality subject to a proper and reasonable use of its waters for domestic, agricultural, and manufacturing purposes, and he is entitled to use it himself for such purposes, but in doing so must not substantially injure others. In addition to the right of drawing water for the purposes just mentioned, a riparian proprietor, if he duly regards the rights of others, and does not unreasonably deplete the supply, has also a right to take the water for some other proper purposes. The most important of these, irrigation, is the subject of another chapter. If a landowner uses the water of a stream in a reasonable and lawful way without malice or negligence and an injury results to his neighbor below, he is not answerable in damages. A public water company owning land upon a stream cannot, without making due compensation, prevent an upper landowner through whose pasture the stream flows from pasturing his cattle in that pasture in an ordinary way, even though the stock fouls the stream An upper landowner has a perfect right to use the bordering stream in a proper and reasonable manner, although in doing so he makes its water unfit to drink. For example, he cannot be denied his right to bathe in the stream, that is, without condemnation and compensation, because a municipality lower down takes its water supply from the stream.

272. Riparian Duty to Refrain from Polluting the Stream.—A riparian proprietor will not be allowed to pollute the stream on which his land borders by casting into it waste, chemicals, or foreign noxious and offensive matter from mills, mines, or factories to the damage of a lower owner. A lower proprietor is entitled to an injunction against an upper owner who persists in polluting the stream. A city or town which discharges its sewage into and pollutes a natural stream so as to render its water unfit for domestic use is liable in damages for the nuisance to a lower proprietor who suffers in consequence. A dairy man owning land upon a stream, who needs a constant and an abundant supply of pure and wholesome water for his stock, may recover damages from a prison association owning land and maintaining a prison upstream and continually polluting its waters with discharges from baths and privies of several hundred prisoners.

273. Riparian Right to Access and Wharfs.—Every riparian proprietor is entitled to the navigable part of the water in front of his land. The measure of damages for cutting off an upland owner's access to a river in front of his land is the difference in the rental value of such land with and without the access. A riparian owner has a right to build a wharf or pier between high and low watermark in front of his premises. The right of a riparian owner upon a floatable stream to build a dam and divert the water for power is limited to the extent to which he can do so and not interfere with the rights of the public. The governmental power of the state over waters is never lost, and any regulation by statute of riparian rights which makes for the general advantage of the riparian proprietors will be upheld by the courts as a reasonable exercise of that power. A riparian right is not lost by neglect to use or exercise it.

274. Surface Waters Defined.—Ordinarily, surface waters originate in falling rains or melting snows, but overflows from streams in times of freshets are surface waters. Surface waters are of a casual and vagrant character, oozing through the soil, diffusing themselves over it, and following no particular course. They are waters that lie upon, overspread, or percolate the soil and flow in no particular direction. Water from rains and melting snows spreading over the ground is surface water until it converges into a defined channel in which thenceforward it continues to flow. Surface waters include water carried off by surface drainage; they are such as are shed and passed from the land of one person to another without having any distinct or defined channel.

A pool in a hollow filled by rains that falls on neighboring highlands, and which has no outlet and parts with its water only by evaporation and seepage, and occasionally dries up altogether, is surface water.

275. Disposal of Surface Water.—The right one has to have water flow to or from his land or mill over and across the land of another is an example of an incorporeal hereditament. The owner of the upper of two adjoining tracts of land has a natural easement to have the surface water which falls upon his land flow off to the lower tract, and the owner of the land next to a river with a levee upon its bank has an easement to have the seepage water flow unobstructed from his to adjoining lower land. Every landowner may turn surface water away from his land to his neighbor's, and the neighbor has no remedy except to pass it on; nobody is subject to an action for deflecting surface water from his own to lower land in the proper use and improvement of his own land, unless he is negligent or vindictive; the recipient must pass it along. At common law, surface water was always regarded as a common enemy which every landowner for the protection of his own property was at liberty to cast upon neighboring land even if thereby he damaged the latter. And in some states, this rule of the common law still prevails; in other states, the rule has undergone some modification. In New Hampshire, a landowner's right to defend his land from surface water is restricted to what is reasonable in the circumstances and having in view the effect of his acts upon neighboring land; and in Iowa, the right to interfere with the surface water is limited by the rule that one who improves his own land must do it in such a way as to cause his neighbor no unnecessary injury. This is also the rule in Nebraska. The rule undoubtedly is, according to the Illinois Supreme Court, that the owner of a higher tract of land has a right to have the surface water that falls or comes naturally on his land pass off through natural drains upon or over the adjoining lower lands; and he has a right, also, by ditches and drains to conduct such surface water into the channels which nature has provided, even though he thereby raises the quantity of water thrown upon the neighboring land; but he has no right to cut away natural barriers to let down water upon the adjoining lands which naturally would not flow in that direction.

276. Restrictions on the Disposition of Surface Waters.—The right of a landowner to cast surface water upon a neighbor's land does not authorize him to gather it in basins and discharge it in floods by artificial means. No landowner has a right to concentrate surface water and throw it bodily upon his neighbor's land. Any one who collects surface water in artificial channels and casts it upon his neighbor's land commits a nuisance for which he must answer in damages; but one who owns a hill slope at the foot of which is another's mill pond is not liable for filling the pond with his surface water in the course of cultivating, manuring, and draining his land in the ordinary way of husbandry.

A landowner has no right by means of drains to and along a highway to cast surface water on his neighbor's land on its way to a ravine which might have been reached directly from his own premises. If there is a drain or watercourse at hand, surface water must be sent into it and not cast upon neighboring land. Although the owner of highlands may not collect the surface waters in one place and cast them in mass upon adjoining land, yet he may guide and quicken their flow by artificial means into hollows and along gullies formed by nature, so long as the increased flow does not deviate them from the natural course. A landowner acting in good faith in improving and tilling his land, and by good husbandry, may fill in sag holes upon it, so that surface water will not gather or remain there, even though the result is that such water finds its way in greater quantities to the adjacent lowlands; but he must not by artificial means collect the water of pools, ponds, or basins on his land and throw it in a body on the land of his neighbor. Surface water flowing naturally in a defined course toward a nearby stream must not be obstructed or interfered with so as to be cast back to the injury of the land which it is leaving.

277. Underground and Percolating Waters.—Water naturally percolating through the soil is a part of that soil, and percolating subsurface water which does not flow in a natural channel as a defined stream may be intercepted and diverted by a landowner under whose land it is found. A grant of a spring does not by implication convey percolating water which feeds it before it reaches the spring. A landowner has an unrestricted right to dig a well upon his own land for his own use, and if by doing so he draws away underground waters from his neighbor's well, he is not liable for the damage; he is entitled, also, to make a reasonable use of a stream flowing beneath the surface of his land, even though it supplies his neighbor's spring or well; but he has no right to make merchandise of the water drawn from his well if by doing so he deprives his neighbor's well of its supply. No landowner will be permitted to draw, collect, or divert underground waters on his own lands not needed for any useful purpose and merely to waste them wantonly to the injury of his neighbor's spring. A landowner may tap underground water upon his land for any useful purpose without incurring any liability to other landowners in the neighborhood whose wells and springs are depleted by his acts, provided he diverts only percolating waters and does not interfere with any underground watercourse or subsurface stream. A subterranean stream flowing in a defined channel may no more be diverted or polluted by the owner of the overlaying land than may a surface stream by the riparian proprietor. A surface landowner who permits offensive and polluting fluids to soak into his soil and impregnate subsurface waters that feed the wells and springs of his neighbors, making them disagreeable, unwholesome, and unfit to use, is liable in damages. One who buries on his own land the carcass of a dead animal, which pollutes his neighbor's spring, is, however, liable to that neighbor only if the circumstances are such that a reasonably prudent person ought to have anticipated such an effect. The escape from a pipe line of oil brought from a distance is not a necessary and natural incident to the transportation of oil, and when an injury is caused by such an escape by percolation to adjacent land, the owner of the pipe line is liable for maintaining a nuisance, regardless of any question of negligence.

278. Ice.—Ice which forms in a stream belongs to the owner of its bed. It belongs to the owner of the soil under the water on which it forms, whether that water is wholly or only partly upon his land. The ice, however, which forms upon overflowed land taken by a public water company by right of eminent domain on condemnation proceedings belongs to the corporation and not to the landowner. The rights to ice formed upon a stream are the same as those to the water of that stream. The right to cut and remove ice from an unnavigable stream belongs to the riparian proprietor, who may exercise it freely for his own use and for storage or sale, provided that he does not infringe in any way upon the rights of the lower proprietors by sensibly diminishing the flow of the stream. Natural ice is personal, not real, property and belongs to the tenant and not to the landlord, unless it is reserved in the lease. The owner of land on a public river or lake, even when he has a grant from the state of the land under water, has no exclusive right, as against individual members of the public, to the ice which forms in front of his premises. The right to take ice from public navigable waters belongs to all the people alike. But this common right does not warrant the cutting and removing for sale of such large quantities of ice as to lower the natural level of the water. Staking off the banks and the ice upon a public stream or body of water long before the ice is ready to cut or thick enough to harvest, with the purpose of garnering it later when it becomes merchantable, is not sufficient for a legal appropriation; it is otherwise, however, when the ice is in a state fit for immediate sale and the intention is to cut and remove it at once.

279. Liability for Casualties.—The owner of a pond in which a boy drowns while skating or bathing is not liable for his death, particularly where the boy had no license or invitation to go to the pond and the landowner had no knowledge of his presence there. But, although this is so, even if no precautions have been taken to guard the pond and keep children away from the water, it is none the less wise for a landowner upon whose land there is a sheet or stream of water to which children have access to take some little pains to prevent accidents, as otherwise it may be both troublesome and costly to escape liability. It has been held that one who maintains an unprotected and dangerous reservoir of water in an open field near a highway where children resort to play is liable for the death by drowning of a child who fell into the water while at play. And the owner of a deep, unguarded pond near a highway, in which a horse was drowned in consequence of taking fright at some goats and backing off the road, was not allowed to escape liability for the death of the animal upon the plea that it would not have happened if it had not become frightened. Although it is certainly negligence of an actionable kind to leave unguarded a hole made by cutting ice upon public waters near a line of travel, in disobedience to a statute, it does not make the person who left the hole that way liable for the loss of horses which plunge in and are drowned while running away, unless the guard required by the law would have prevented the casualty had it been in place.

280. Essential Features of Drainage Contracts.—Any contract which specifies something forbidden by law is void.

281. Material Changes.—A drainage contract is usually protected by a bond, and no material change can be made without first securing the permission of the bondsman. If such changes are made without the knowledge and consent of the bondsman, then his liability ceases under the law.

282. Engineer's Authority.—The engineer has certain definite powers concerning the approval, acceptance, or rejection of work. In case of a dispute, it is up to the courts to decide whether or not the engineer shall act as arbitrator. If it is a question of a technical character, the engineer's decision usually stands, but if it is a question of non-technical facts, witnesses will be called in to settle the point at issue.

283. Agreement.—A contract to be valid must be so drawn that each party to the contract understands it to mean the same thing. Contracts are interpreted according to the common usage of the words in the vicinity where they are drawn, and that is what holds.

284. Misrepresentation.—Misrepresentation does not render a contract invalid except when made intentionally. If one can prove that he has been a victim of intentional fraud, then he is justified in bringing suit. Fraud makes all contracts invalid if proved, and the right of action lies with the injured party who can either enforce such a contract or not as he chooses. The injured party, however, must make known his intention of bringing suit as soon as he discovers the existence of fraud. Any great delay is interpreted to mean that he has accepted the contract in spite of its fraudulent features. Failure to read and understand a contract is negligence on the part of the person failing to understand. Any one who fails to understand a contract as he has read and interpreted it in the terms of community usage of words has a right to enter suit.

Once a man bought a farm at the price asked, and the seller guaranteed that there was a natural method of draining the farm. The purchaser took the farm, made payments upon it, and constructed improvements. When he was ready to drain it, however, he found that there was no natural outlet that he could use. The only outlet that did exist was on an adjoining tract of land which he had no legal right to use because he would have had to go across his neighbor's property in order to get to it. The decision of the courts hinged upon the common usage of the phrase *natural outlet* in that community.

285. Consideration.—Old forms of deeds specified that a certain piece of land was sold for $1 and "other legal consideration." Contracts, to be valid, must have a legal consideration. It is not necessary that the consideration be adequate. If a person guesses too low in putting in a bid or selling a piece of property, that fact has no effect upon the legality of the contract. Sometimes, when final settlements are made, the question arises as to whether a contractor should take less than is due him or nothing at all. Under these circumstances, the contractor can accept whatever money is offered and then enter suit for the balance.

286. Assignment.—There is a clause in most contracts which specifies that the contractor cannot sign another contract subletting a part of the work without the consent of the other party to the original contract. He must also secure the consent of his bondsman and require a new bond covering the second contract.

287. Interpretation of Contracts.—Contracts should be drawn up stating the terms of agreement in simple, concise language. The simpler a contract is the harder it is to break, because the courts interpret it the same as any ordinary individual would do. Any ambiguity which makes the meaning of any part or clause doubtful may cause the whole contract to be invalid. If the contract is printed with blank spaces to be filled in in writing, such writing takes precedence over the printed matter. If both general and specific terms are used, the specific terms hold good over the general terms. A definite, specific description of the manner in which a certain piece of work shall be done, for instance, takes precedence over a general clause stating that all work shall be done in a good and workmanlike manner. Words that are ambiguous in meaning will be construed more strictly against the person making the contract, *i.e.*, the "party of the first part."

288. Principles of Construction.—First, determine exactly what it is that should be agreed to. Second, draw up the contract to state that agreement in the simplest possible terms. Third, see that no conflicting or ambiguous statements are included. Do not specify in one part of the contract that a certain thing is to be done in a certain way and then, in another part of the contract, say that it shall be done in a different way. Above all things, be consistent.

289. Subchanges and Agreements.—Any changes that may be desired can be made in a contract if both parties agree. No material change can be made, however, unless the difference in cost entailed by such change is added to or subtracted from the original contract price. And, as already stated, any such change must also be approved by the bondsman. It is always best to have everything concerning the agreement in writing, although, in some states, this is not strictly required. When statements and agreements are not recorded in writing, it would be difficult to prove that they were ever made, in case of a dispute.

290. Discharge of Contracts.—Contracts are usually discharged automatically upon satisfactory completion of the project. They may, however, be discharged at any time by mutual agreement. Sometimes, contracts are discharged by breach on the part of either party, in which case, the injured party may secure redress by a suit for damages, but a judgment is valuable only in so far as the guilty party is financially responsible. Nearly all contracts contain clauses releasing the contractor from his agreement to perform certain work in a certain way by a certain time in case he should become powerless to perform such work on account of events over which he has no control, such as storms, floods, earthquakes, or other "acts of God." A great many corporation letterheads carry a printed statement to the effect that the company will not be responsible for any delays or accidents caused by strikes, floods, etc. The courts have held that, in order to secure immunity under such a clause, the circumstances must have been such that no human being could possibly have completed the contract. The mere fact that the individual contractor did not complete it is not *prima facie* evidence that it could not have been completed by some one else under the same circumstances.

Any act of God which does not preclude the possibility of completing the work but which does make it more expensive is a just and proper hazard against the contractor, and he must pay the additional cost. If the work is not completed by a predetermined date, some contracts specify that the contractor must pay the owner a stipulated sum of money for each day overtime, but if the contractor can show that this payment was clearly intended as a penalty, recent decisions have held it to be invalid. In order to legalize such a clause, some contracts now specify that if the work should be completed before a given date, the owner shall pay the contractor a certain amount per day from the time the work is actually completed until the date on which it was supposed to have been completed and that, on the other hand, if the contractor does not complete the work by the said time, he must pay the owner so much for each day overtime. This feature is called a *bonus*.

If a contractor should be guilty of a breach by failing to complete the work, the owner must pay for the portion that is completed, provided it is in a usable condition.

291. Specifications.—Specifications may be either general or specific. General specifications refer to the legal phases of the work, and they are governed by the same principles of law as contracts. Specific specifications should state what is to be done, what materials are to be used, and how the work is to be done. Chapter XXVIII contains a model set of specifications that is suitable for drainage work.

The character and ability of the engineer on a given piece of work have some influence on the bid of contractors. If he is exacting, they bid high; and if he is careless, dishonest, or incompetent, they can afford to bid low. Contractors generally make it their business to discover the engineer's reputation before submitting their bid.

When formulating specifications the thing to do is to state as simply and clearly as possible exactly what is wanted and how it is to be done. Avoid long-winded, stilted verbiage that serves only to clutter up and becloud the real issues.

292. Where Contract Blanks May Be Obtained.—Blank forms for contracts are usually kept on file at the courthouse in every county seat in the country, where they are easily available. Any extra or special provisions not provided for on the regular form may be typewritten on a separate sheet and attached to the form.

CHAPTER XIX

EXPLOSIVES AND THEIR USE[1]

In recent years the value of explosives for agricultural uses has become increasingly apparent. Explosives, when used alone, are quite effective for such things as subsoiling, stump lifting, rock blasting, and ditch digging through unfavorable ground which would be difficult to handle by ordinary methods. When used in smaller quantities for loosening stumps which will be removed later by machines or pulled by teams or tractors, they are also very economical. Explosives are so useful and harmless when properly handled and so dangerous when improperly understood that considerable space is devoted in this chapter to their composition, characteristics, and correct manipulation.

293. Kinds of Explosives.—For blasting purposes, there are scores of different kinds of explosives, with as many different names. The one most familiar in America is dynamite. Other names are farm dynamite, stumping powder, Judson powder, giant powders, blasting gelatin, etc. Nearly every one of the explosives designated by these names is made in several strengths and in qualities to suit varying conditions. In addition to this, some of the names are used to designate not only one certain explosive but also several widely different ones. This is particularly true of the names *dynamite* and *powder*.

All blasting explosives are not made from the same ingredients, and they differ a great deal in many other ways besides quality, as quality is generally understood. Nearly every standard kind and grade is of excellent quality, for some particular purpose and condition, and practically every one can be classed as of poor quality for conditions and purposes to which it is not suited. The main differences are ones of strength, quickness of action, sensitiveness, resistance to cold and to water, and cost.

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[1] Publications of the Institute of Makers of Explosives as well as those of the makers were drawn on liberally for much of the material in this chapter.

Black blasting powder has been known and used for several hundred years, and it is practically the same in composition today as it has been for a long time. It is composed of saltpeter or nitrate of soda, sulphur, and charcoal.

Dynamite and high-explosive powders bear little or no relation to black blasting powder. They are more powerful, detonate with much greater rapidity, and have a greater shattering effect. The first dynamite was used in Europe by mixing nitroglycerin with a light, spongy earth and packing the mixture in paper tubes as cartridges of dynamite are packed today. Nitroglycerin itself is a wonderfully efficient explosive when it can be controlled, but it is so sensitive to shock, that it must be mixed with absorbents and treated to make it safe to handle. As other explosive chemicals became better understood, it was found of advantage to substitute combustible materials such as wood pulp for the light earth used to absorb the nitroglycerin, and, more than that, the nitroglycerin itself has been displaced in varying degrees by ammonium nitrate and other materials. Some explosives are in use containing very low percentage of nitroglycerin, while certain effective types of ammonium nitrate explosives contain no nitroglycerin at all.

294. Action of Explosives.—The power of an explosive and its violence are two different qualities. An explosion, in this connection, is the sudden transformation of a solid into a gas which occupies a much greater space. The power is due to the volume of the gases. If a pound of a certain explosive gives, for instance, 1,000 cubic feet of gas when completely fired, while a pound of another explosive gives 500 cubic feet, the power of each will be in direct proportion to its gas volume. The violence of the explosive, however, depends not on the volume of the gases but on the speed of conversion of solid into gas. If they are comparatively slow in forming, and in forcing their way out of confinement, they will cause large cracks in the material and escape through them, pushing the material aside. If they are very fast, they will grind and pulverize everything with which they come in contact and throw out the whole side of the confining material but will not cause so much cracking. By way of illustration, take soil blasting for tillage purposes. There is no object in violently grinding the earth at one spot while the surrounding earth which might be reached is left untouched. A proper explosive for this purpose is one that will have sufficient action to lift and shake the soil and extend its effects long distances. For an example of the other extreme, take mud capping rocks. For this work, the explosive cannot be too violent in action. The gases backed up by the rapidly yielding wall of air on one side of them must strike the rock a crushing blow in a minimum of time.

295. Strength of Explosives.—Nitroglycerin or straight dynamites and ammonia dynamites for all practical purposes are of equal strength when of equal markings. The strength is indicated accurately by percentage figures.

296. Explosives and Water.—Nitroglycerin explosives resist water better than ammonia explosives, but if the cartridge wrappings are not broken or opened, ammonia dynamite or powder can be loaded in wet holes satisfactorily. The firing should not be delayed any longer after loading than necessary, and it is wise to plan the work so that it may be done within a half-hour. Storage in a damp place will weaken explosives, especially ammonia explosives.

297. Firing Explosives.—Black powder is fired by a spark, while dynamite cannot be so fired but requires a combination of shock and heat such as is produced by a detonator. There are great differences in the nature and effect of the explosion of any dynamite, due to variation in the way it is fired. The kind and amount of gases produced by any high explosives depend on the kind and amount of shock used to fire the charge as well as its confinement. If a piece of unconfined dynamite is lighted with a piece of fuse without a cap on, the dynamite will burn rapidly without exploding and make a dense smoke which has a bad smell and produces severe headaches. This is simple combustion. If the piece of dynamite is confined closely and lighted in the same way, it will explode but will give off similar bad fumes. If a weak cap is used on the fuse, or the dynamite is set off by a fall, it will be partially detonated and will explode with considerable force, but it still will give off bad fumes and smoke. The same piece of dynamite fired with a No. 6 or No. 8 cap will be completely detonated and will explode with great violence and force, even when unconfined except by air, and will give off very little smoke. The last-mentioned explosion is detonation. It is produced by violent shock in connection with intense heat. Nitroglycerin is five times as strong as black powder when exploded by fire and ten times as strong when detonated. In the case of any detonation at less speed than the greatest for any particular explosive, the gases formed are more noxious or poisonous and less effective as blasting agents. It is the nature of the initial detonation of the explosive right around the cap which governs the nature of the explosion of the whole charge. Air spaces about the cap in the cartridge of explosive cushion the blow. Lack of confinement of the cartridge has a similar effect. Both reduce the effectiveness of the charge.

298. Where to Use Different Kinds of Explosives.—The following table will suggest the type of explosive best suited for different kinds of agricultural work:

Stone blasting—mud cap	50 or 60 per cent nitroglycerin or ammonia dynamite
Stone blasting—undermining "snake holing"	To break, 40 per cent dynamite; to throw out, any 20 per cent strength dynamite
Stone blasting—block hole	To shatter, any high-percentage dynamite; to break, 20 per cent strength
Soil blasting	20 per cent ammonia dynamite
Ditching—electric firing	Any 20 to 40 per cent strength; for loose, dry ground, high-percentage nitroglycerin
Ditching—propagation method	50 or 60 per cent nitroglycerin
Stump blasting—medium to heavy soil	20 to 30 per cent dynamite
Stump blasting—dry sand or light soil	40 to 50 per cent dynamite

299. Hauling Explosives.—The law requires prompt removal of explosives and blasting accessories from freight stations. Persons expecting shipments should arrange with the freight agent or station master to be notified immediately of their arrival and should remove them within 24 hours.

When transporting explosives by team, always keep the wagon boxes thoroughly clean. When using an open wagon, protect the load from sparks and rain with a robe or canvas cover. Lay the cases of explosives flat, in such a way that they will not shift. Never haul detonators and explosives together.

300. Storing Explosives.—As soon as explosives are received, they should be stored in a dry, properly ventilated building, safe from fire and flying bullets, and far enough away from dwellings or roads to prevent loss of life should they be accidentally exploded. They should be kept under lock and key, where children or irresponsible persons cannot get to them.

If large quantities are to be stored for some time, a dry, well-ventilated, fireproof, and bullet-proof magazine located in an out-of-the-way place should be provided. Fuse, wire, thawing kettles, and blasting machines may be stored in the same building with the dynamite, but blasting caps must never be stored in the same building. It would be possible to explode them accidentally by a hard shock or jar which would not explode dynamite. If detonators were to explode by themselves, they would not do so much damage as they would if they were to explode in the same room with dynamite and cause the dynamite to explode also.

301. Using Explosives.—When ready to use the dynamite, open the box or case with a hardwood wedge and a mallet. Never take to work more than the day's supply.

When large quantities of high explosives are handled with bare hands, they nearly always cause a headache. Cheap cotton gloves should, therefore, be worn. The gloves should be destroyed before they become damp and sticky, and clean ones provided.

302. Frozen Explosives.—Very few of the modern explosives freeze at ordinary temperatures; hence, they are not often in need of thawing; but when they do freeze, the following is important: Thawing frozen explosives is dangerous, because explosives when frozen are very much more sensitive to friction and to blows of tools. Frozen cartridges may explode when broken in two, when pushed into a hole with a tamping stick, when wrappings are cut with a knife, or when cap holes are punched. The only safe rule is never to cut, puncture, or use the frozen cartridges of high explosives until they are thawed. Thawing is a dangerous operation when not done right; many accidents have occurred from improper methods. Do not attempt to thaw dynamite in hot water or steam or by putting it on hot stoves or stones. To do so will cause the nitroglycerin to leak from the paper wrapping before it can be taken up by the absorbent material, and serious results will occur. Use only a dry warmth, and set the limit of the thawing temperature at 110°. Use no heat of any kind that cannot be controlled with certainty.

303. Explosive Accessories.—For firing charges of explosives, certain accessories are needed. If the charge is fired by electricity, electric blasting caps, a blasting machine, and leading wire are necessary. Otherwise, blasting caps, fuse, and a cap crimper are used.

304. Blasting Caps.—Blasting caps used for firing or detonating charges of high explosives are similar to the primers in a gun shell, only many times larger. The No. 6 cap, which is the size recommended for detonating most high explosives, is a copper cylinder 1½ inches long and a little less than ¼ inch in diameter, closed at one end, and loaded with 1 gram of fulminating mixture. The No. 8 size is longer and contains a heavier charge. Nothing smaller than a No. 6 should be used with any of the explosives used on the farm, because strong caps

Insure complete detonation.
Increase the execution of the explosive.
Offset, to some extent, deterioration, due to the improper storage.
Prevent the loss of the charge by burning.
Minimize the fumes.

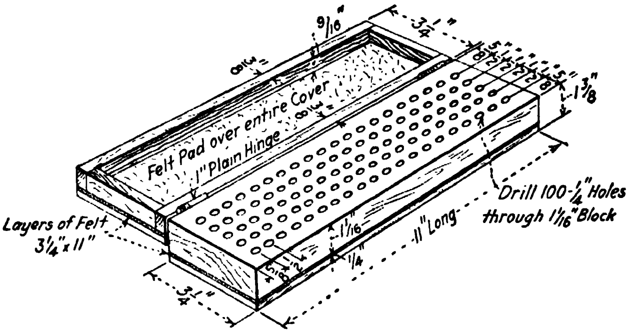
9/16"
3/4"
3/8"
5/8"
1/2"
5/8"
1 3/8"
Felt Pad over entire Cover
3/8"
1" Plain Hinge
Drill 100-1/4" Holes through 1 1/16" Block
Layers of Felt 3 1/4" x 11"
1 1/16"
11" Long
1/4"
5/8"
1/2"
3/4"

FIG. 113.—A safety box for storing and carrying blasting caps. Keep it locked.

Blasting caps are packed in tin boxes containing 100 caps. From 5 to 50 boxes are packed in wooden cases for shipment. They may be exploded by shock, heat, or sparks and so must be kept away from fire and always handled carefully. They are weakened by moisture and, therefore, must be stored in a dry, cool place.

A. J. McAdams[1] gives the following suggestions as to the handling of blasting caps in the field:

> When using blasting caps in the field, the box should remain covered at all times and the caps should never be exposed to the direct rays of the sun. The caps should be kept tight in the container by packing with paper or cotton and they should be kept in an upright position with the

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[1] *Univ. Mo. Agr. Expt. Sta., Cir.* 158.

open end up. To take a cap from the box, tip the box to one side until a cap can be picked out with the fingers. Never use a nail, wire or match to remove a cap and never investigate the explosive in the cap. Be careful of cigar, cigarette or pipe ashes when handling blasting caps. Caps should be stored in a dry cool place and if possible under lock and key. Keep the caps where children cannot get at them.

A safety cap-box for storing and carrying caps can easily be made on every farm. The box is made from any soft wood block and an old felt hat. Figure 113 gives the necessary dimensions. The box should be large enough to hold 100 caps.

305. Dampproof Fuses.—A safety fuse is a thin chain of powder wrapped in a covering of jute or cotton yarn or tape. It is used to bring a spark to a cap in detonating a charge of high explosives. Many grades are made for different purposes. In blasting on a farm, dampproof fuses are generally used for dry or moist work, and waterproof fuses for wet work.

Fuse is packed in a double roll, one roll fitting inside the other, and each 50 feet long. Each double roll of 100 feet is wrapped separately. It is packed for shipment in wooden cases containing from 500 to 6,000 feet.

Fuse should always be kept dry and stored in a cool, dry place. If stored in a damp place, it becomes damaged after a time and may fail to burn. If stored in a hot, poorly ventilated place, as, for example, close under the roof of a small shed, in summer time, it may be damaged either by becoming soft and oily or by drying out and becoming so hard and brittle that it will break when unrolled. Fuse may also become stiff and brittle in cold weather. When in this condition, it should be warmed before being unrolled.

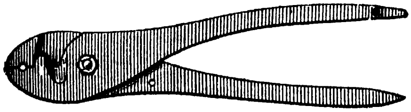
FIG. 114.—Cap crimpers.

306. Cap Crimpers.—Cap crimpers are made especially for fastening caps to fuses securely and are necessary wherever blasting is done with cap and fuse. Other means of crimping sometimes used are unsatisfactory and dangerous.

Crimpers make a crimp which is so fine and of such a shape as to be of aid in making the cap waterproof. Figure 114 shows a style which is supplied with a pair of jaws for cutting fuse.

307. Electric Blasting Caps.—Electric blasting caps, like caps and fuse, are for detonating charges of high explosives. The explosive charge is contained in a copper cylinder quite similar to the ordinary blasting cap, but the explosion is caused by heating a fine alloy wire connecting the ends of the pair of small copper wires instead of a powder spark from fuse. In strength they are the same as the ordinary caps of the same number.

Electric blasting caps, like blasting ordinary caps, can be exploded by shock or heat. In handling and storing them, the same precautions as are given for blasting caps should be strictly observed. Never attempt to pull the wires out of their setting or investigate the contents of these caps.

The wires attached to the caps range in length from 4 to 20 feet, but it is seldom that anything longer than a 4 or 6 foot length will be needed in farm work. The caps are packed in lots of 50 in strong paper cartons. Ten cartons are packed in a wooden shipping case.

308. Blasting Machines.—Blasting machines are small, portable electric generators built for generating current to fire electric blasting caps (Fig. 115). The mechanism is operated by a rack bar or plunger protruding through the top of the machine. The bar is pulled up as far as possible and then forced down with a quick, hard thrust. This sets in motion the armature and builds up the current until the bottom is reached, when the connections are automatically completed and the current flows out through the leading wires to the electric blasting caps placed in the charges of explosives.

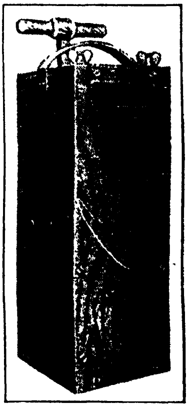

Fig. 115.—Electric blasting machine.

When using the machine, the rack bar should be forced down as hard and quick as possible, the operator using both hands and all his weight. The machine should be placed on a firm and level place to prevent it or the operator from tipping over.

These machines are built for rough use, and every precaution is taken to make all parts strong. They are likely to be damaged, however, by exposure to the weather and should be wiped off and put in a dry place when no longer in demand. They should be tested occasionally with a rheostat, to be sure that they are working up to standard capacity.

Blasting machines are built in six sizes (Table 23), so that a selection can be made to suit the demands of all classes of work.

TABLE 23.—SIZES AND CAPACITIES OF BLASTING MACHINES

Size of machine	Capacity—number of electric blasting caps, copper wire	Used for
Pocket	1 to 3	Stumping and boulder blasting
No. 20	1 to 10	Stumping, boulder blasting, and small ditch jobs
No. 30	1 to 30	All classes of general work
No. 50	1 to 50	Large ditches
No. 100	1 to 100	Large ditches

309. Leading Wire.—Leading wire is insulated copper wire used for conducting the current from the blasting machine to the blast. It has a strong insulation especially suited to the rough usage that it must receive.

310. Connecting Wire.—Connecting wire is used to complete the circuit when the holes in the charges are placed too far apart for the electric blasting cap wires to reach. It is sold in 1- and 2-pound spools. A 1-pound spool of No. 20 wire holds about 210 feet.

311. Galvanometer and Rheostat.—Most dynamite manufacturers sell an instrument called a *galvanometer*, for testing blasting circuits. This is an ingenious instrument, of use in determining whether or not a blasting circuit will transmit the current and also in locating breaks in the circuit. A simple instrument used for testing blasting machines is called a *rheostat*.

312. Tools for Agricultural Blasting.—Certain tools are needed for loading and making the bore holes. Those used for agricultural blasting are few and simple. They are often to be found on the farm, but, if not, they can quickly be made at little cost.

A tamping stick is used to tamp the soil on top of the cartridges and to place the cartridges in the bore hole. It is also of use in trying out the holes before loading, to see that they are of sufficient depth and not stopped up. It must be of wood, with no metal parts. Its length should be a little greater than the depth of the holes to be loaded, and its diameter not larger than that of a cartridge of dynamite, 1¼ inches. An excellent tamping stick can be made of an old hoe, rake, or broom handle or, when a very long one is needed, of a sapling.

A driving iron is used for driving holes, for subsoil blasting and tree planting, for stumping, for ditching in hard soil, and for road grading. It should be of 1½-inch round or octagonal steel and a few inches longer than the depth of the holes (Fig. 116). The point should be drawn out in the shape of a rather blunt pencil point. It is driven into the ground by means of heavy hammers or sledges and loosened by pounding on the sides, or using the method illustrated in Fig. 117.

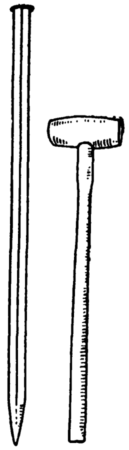

FIG. 116.—Driving iron.

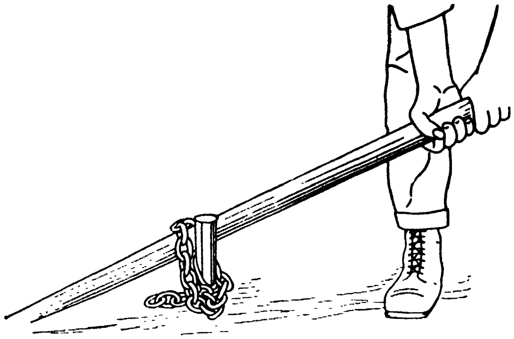

FIG. 117.—Method of removing driving iron from ground.

A blasting spoon, made by flattening and cupping the end of a ¼-inch steel rod (Fig. 118), is convenient for enlarging bore holes and also for removing pebbles from holes.

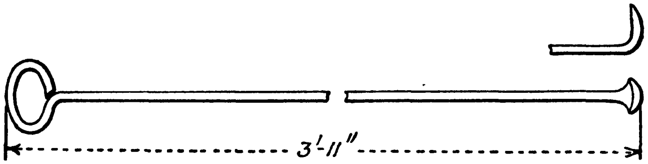

FIG. 118.—Blasting spoon.

A punch bar is used for making holes in soft or swampy ground. It is made of 1¼-inch galvanized-iron pipe as per dimensions given in Fig. 119. The bar is used principally in making holes for the blasting of ditches.

A ditching bar, which is particularly adapted to use in sand and gravel soils, is shown in Fig. 120. The bar is similar to the regular punch bar except that it has a removable core which allows the explosive to be put in the hole before the bar is removed from it. This bar was designed by A. J. McAdams.

The soil auger is used for making holes in stump and boulder blasting, for other holes hard to make with a punch, and for deep drainage. While it can be used for subsoiling, it is not so fast as the driving iron. It should be 1½ or 2 inches in diameter.

The bit may be welded onto a solid steel shank which will make the auger at least 5 feet long, if it is for stump or boulder blasting. For deeper holes, the shank can be made of ⅜- to ½-inch gas pipe in sections of 2 or 3 feet in length, so that it can be extended by adding more sections. The handle is made of a pipe tee and two short pieces of pipe for grips.

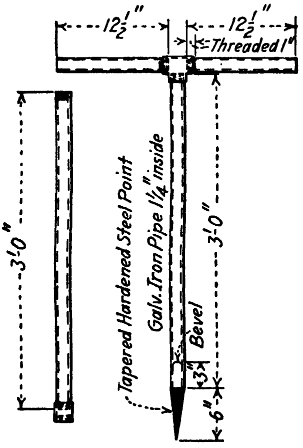

FIG. 119.—Punch bar for making holes in soft ground. (*Courtesy of A. J. McAdams.*)

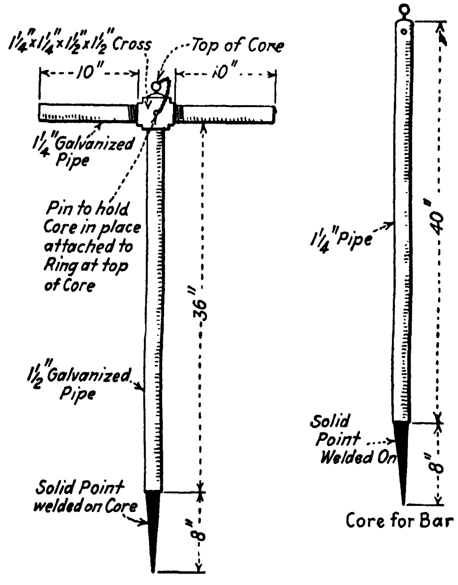

FIG. 120.—Ditching bar for sand and gravel. (*Courtsey of A. J. McAdams.*)

A good type of auger head can easily be made by a blacksmith. The shank is flattened out and welded into a sleeve socket. The handle proper should be of wood and only long enough to make turning easy.

Worn-out wood augers make fairly good soil augers for small jobs, but where there is much work to do, it will pay to get the special soil augers described.

313. Priming with Cap and Fuse.—The most satisfactory and reliable way of inserting a blasting cap and fuse in a cartridge is on the side of the cartridge.

The first step is attaching the blasting cap to the fuse.

Attaching Blasting Cap to Fuse.—In doing this, the fuse should be cut long enough to give the blaster time to reach a safe place before the explosion. Fuse burns on an average of 2 feet per minute, and, in addition to allowing sufficient time, it should reach at least 3 inches out of the bore hole.

Cut the required length from the roll with a sharp knife, hatchet, or cap crimper. The cut should be made squarely across and not diagonally. Sometimes, in cutting, the end becomes flattened, thereby making the end of the fuse too large to enter the blasting cap. When this happens, squeeze the end round with the fingers. Open the cap box and allow one cap to slide gently out into the fingers, but, under no circumstance, pick a cap out of the box with a piece of wire, stick, or other hard substance. See that there is no grit or trash in the cap. Slip the end of the fuse gently into the cap until it is against the charge in the bottom. Do not twist the fuse, as the friction might cause a premature explosion. Then, take the cap crimper and fasten the cap to the fuse with a crimp near the open end of the cap. These operations are not dangerous but should be done carefully. If the primer is to be used in a wet hole, dip it in sealing compound, or smear a little hard tallow, soap, or similar substance around the top of the cap, to insure against water leaking in and ruining the cap before it is fired. Never use oil or light grease, as these will penetrate the fuse covering and ruin the powder in the fuse. The cap is then ready to be inserted into the dynamite.

Priming Cartridges in Side.—This is done by punching a hole diagonally into the side of the cartridge about 2 inches from the end and pointing toward the center, to a sufficient depth to receive the entire cap. The holes can be punched with the handle of a cap crimper or with a wooden awl. One end of a piece of string about 20 inches long is wrapped four or five times around the prepared fuse and cap just a little above the cap on the fuse. The cap is then put in the cartridge, and the loose end of the string wrapped around the fuse and the cartridge four or five times, and the end drawn firmly between fuse and cartridge (see Figs. 121–126).

314. Priming with Electric Blasting Caps.—When electric blasting caps are used, they may be inserted into the dynamite by the method described for caps and fuse. Many blasters,

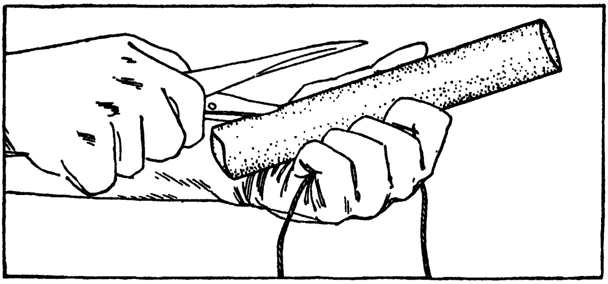

Fig. 121.—First step in priming cartridge. Make hole in the side of the cartridge with the handle of cap crimper so that cap will lie lengthwise of the cartridge. Soften the cartridge if necessary by rolling between the hands. The handle of the crimper is safe to use with explosives now sold. It is made for that purpose.

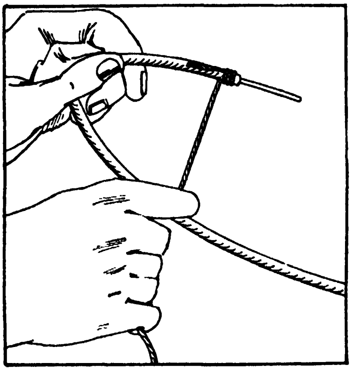

Fig. 122.—Second step. To fasten cap and fuse to cartridge, first with a coarse string about 20 inches long make four or five wraps around fuse a little above the cap. These wraps should cover the end of string so as to grip tightly.

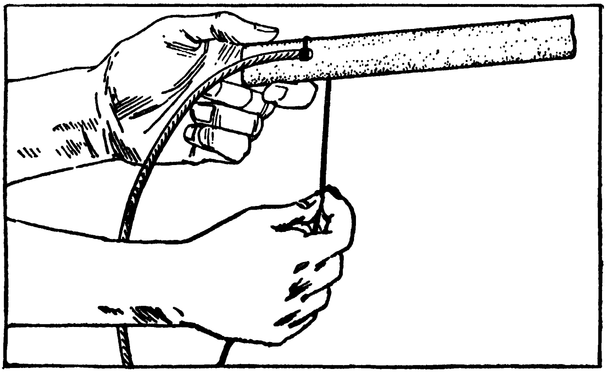

Fig. 123.—Third step. Insert cap and fuse with string attached.

however, prefer to use a slightly faster method, which has been found entirely satisfactory.

Punch a hole from the center of the end of the cartridge in a slanting direction so that it will come out at the side 2 or 3 inches from the end. Bend back the wires about 8 inches from the cap and insert the end of the double wires of the electric blasting cap; loop these around the cartridge (Fig. 127). Punch another hole in the same end a little to one side of the first and straight down. Insert the entire capsule in this last hole, and take up the slack on

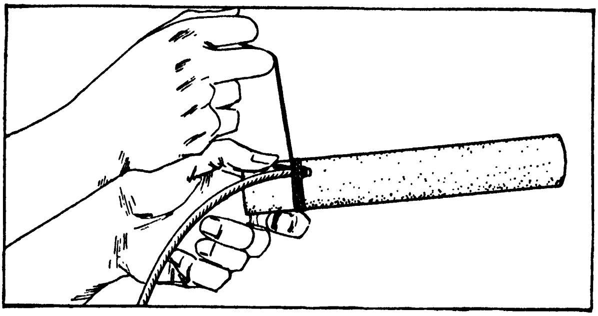

Fig. 124.—Fourth step. Wrap string tight.

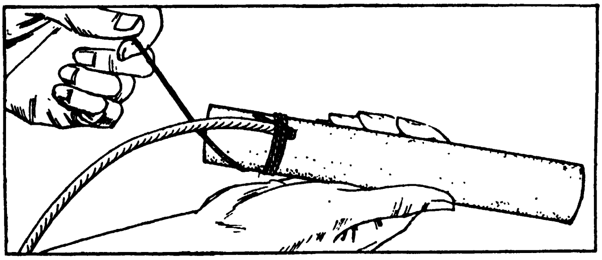

Fig. 125.—Fifth step. Tuck end of string under fuse. Next wrap the loose end of string around both cartridge and fuse above cap three or four times finally drawing the end under between fuse and cartridge. Draw the string tight. An extra turn about the fuse will help hold this end more securely.

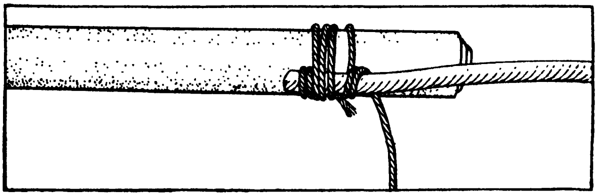

Fig. 126.—Complete. (*Figs.* 121 *to* 126 *from Univ. Wis. Ext. Circ.* 164.)

the wires. In this method, the wires do not cross each other at any point, the capsule is lying nearly in the axis, and the cartridge hangs vertically, so that it is possible to load in the bore hole without its being caught on any roughness (Fig. 128).

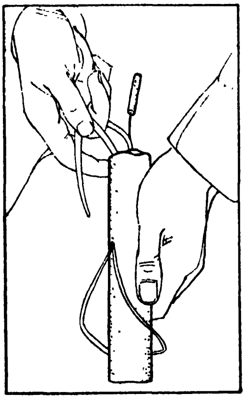

FIG. 127.—Priming with an electric blasting cap.

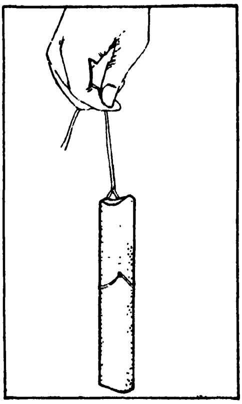

FIG. 128.—Primed cartridge.

315. Loading.—When the cartridge is primed and the hole made, the next thing to do is to load. First, try the hole with the tamping stick to see that it is open and will permit the charge to be placed at the desired point.

When loading a charge consisting only of the half or whole cartridge containing the detonator, as in subsoiling or tree planting, start the primed cartridge into the bore hole and press it gently into place with the tamping stick. See that it is firmly seated in the bottom of the bore hole.

In pressing a primer into place, do not handle it roughly, as it contains the cap and is, therefore, more sensitive and dangerous than an unprimed cartridge.

When the load is to contain a larger amount of dynamite, press the unprimed cartridges into place in the bottom of the hole first, and place the primer with the cap pointed toward the rest of the charge on top. When the hole is dry, and it is desirable to have the charge concentrated in one place, it is a good practice to slit the sides of the cartridges from end to end with a knife so that the dynamite can be compacted into a smaller space. The primer should not be slit. When the bore hole is wet, it is not advisable to slit the cartridges.

In all classes of agricultural blasting, the charge should be pressed firmly into the bottom of the bore hole so that no air pockets are left,, as they weaken the action of the explosives.

316. Tamping.—After the charge is in place, the hole must be tamped, that is, filled to the top with some material, in order to confine the charge closely and to insure its effectiveness. This tamping should be made as tight as possible, so that the gases will not blow out as through the muzzle of a gun.

To guard against danger of prematurely detonating the charge, the first 5 to 8 inches of tamping should not be packed with any considerable force but should be firm. When this amount of lightly tamped material covers the primer, the rest of the tamping should be made as hard as possible, so that no open-air spaces are left, and should extend to the mouth of the hole, entirely filling it. The tamping should be done with the wooden tamping stick. Care should be taken to prevent stones and pebbles from falling into the hole while loading and tamping.

Most clay free from gravel and clods makes good tamping material. Moist sand or moist loam is also good. In wet work, when a foot or more of water covers the charge in shallow holes, it will not be necessary to add other tamping, as the water will hold the charge sufficiently tight.

Before beginning tamping, it is well to measure the depth from the surface to the top of the charge, so that if the tamping must be removed to get at a misfire, there will be no danger of disturbing the primer.

317. Firing by Electricity.—For some kinds of work, electric firing is more effective and economical and practically essential. In general, this is the only way in which several charges in different holes can be fired simultaneously. It is often of great advantage to fire charges at the same time, as each tends to help the other. Large boulders and stumps with spreading roots can be blown out and broken up more thoroughly and with less dynamite if the explosive is distributed in several holes in different places under the boulder or stump and all of these charges are exploded at one time. Groups of stumps standing close together can also be blasted in this way. In order to dig a ditch satisfactorily, it is always necessary to explode a number of charges simultaneously, and in dry soils this can be done only by electric blasting.

Electric firing is to be recommended for all road work or for other blasting when passing persons might be injured.

The equipment needed for blasting by electricity, in addition to the explosive, consists of

Electric blasting caps.
Connecting wire.
Leading wire.
Blasting machine.

When the charges have been primed with electric blasting caps and tamped, the two copper wires protrude from the ground over each charge. These two wires should be separated, and one of them connected to one of the wires of the electric blasting cap in the next hole on one side, and the other to one of the wires of the electric blasting cap in the hole on the other side. In this way, all of the caps should be connected in a row, with one free wire extending from the first charge, and another extending from the last charge. These loose wires are connected to the wires leading to the blasting machine. This method of firing is called *connecting in series.*

If the holes are too far apart for the electric blasting cap wires to reach between them, the wires are joined by pieces of connecting wire.

Connections are all made by twisting bare wire ends securely together. All ends should be scraped with a knife so that they will be free from grease or corrosion when connections are made.

Always be sure that there is a complete circuit of wire offered for the passage of the electric current. Otherwise, the blast will not fire, for the current must pass through each electric blasting cap in order to fire it. Should there be any bare joints resting upon damp ground or in water, or should one bare joint touch another, there is a likelihood of a short circuit through which the electric current will pass instead of around the entire blasting circuit. The bare joints or other uncovered places in the wire can be kept away from water or damp ground by holding up the wire on one side of the joint with a dry stick, block of wood, or stone.

Do not attempt to fire through a long length of leading wire wound in a coil or on a reel. The induction, leakage, or short circuit of current in the coil of wire causes the blasting machine to deliver a slow discharge, which is fatal to proper firing.

The blasting machine should be placed on firm, level ground. The leading wire should be long enough to enable the one who operates the machine to be outside the danger zone. Never connect the wires to the blasting machine until it is time to fire, and keep careless persons from tampering with the machine or leading wire while the shots are being loaded.

When ready to fire, lift up the handle of the blasting machine as far as it will go, and, using both hands, with one quick, hard stroke, push it down to the bottom of the box with a solid thud. Try to knock the bottom out of the machine.

318. Handling Misfires.—The use of reliable explosives and caps and careful priming and charging greatly reduce the chances of misfire.

When a shot does fail to fire, the investigation of the trouble should be placed under the direction of a careful and experienced workman, who should make his examination in a slow, methodical manner before beginning the work of repriming. No other persons should be allowed to remain near him, as their presence or suggestions are likely to cause confusion.

When a misfire occurs, it is never safe to return immediately to the hole. The interval of waiting should be as long as possible, preferably until the next day if the firing is done in the afternoon. In all cases, it should be several hours. In order to avoid wasting time waiting for a blast whose fuse is not even lighted, make certain, when lighting the fuse, that the flame spits out, showing that the powder column is on fire.

When electric blasting caps are used, it is generally safe to go back to investigate the trouble an hour or two after disconnecting the wires from the blasting machine. The investigation should consist, first, of a search for broken wires, faulty connections, or short circuits. If such are found, make the proper repairs, reconnect the leading wires, and operate the blasting machine. Many so-called *failures* are the result of poor connections or of connections being in contact with wet ground or other conductive material.

If the cause of the misfire seems to lie in the hole itself, there are several possible methods of procedure. If the hole is untamped or is tamped with water, make up another primer, place it on top of the charge, and fire. If the ground is soft and wet, drill and load a second hole, which, when fired, will cause the first charge to explode. In doing this, great care must be taken. Such a hole must be far enough away from the charge to make drilling and loading safe but close enough to cause detonation by concussion and to make sure that the first charge will be blown out together with the rock or confining ground. When it is not possible to do this, the tamping can be carefully removed almost down to the charge with a spoon and hardwood probe, a new primer inserted, and the hole retamped. This must be done very cautiously, however, especially when the cap is in the top cartridge of the charge, as the cap may be fired by friction or impact.

319. Blasting Stumps.—The blasting of stumps is materially influenced by several factors, chief among which are character of the root, whether tap or lateral; the state of preservation of the stump, whether sound or partially decayed, freshly cut or green stumps being much harder to blast than those from which the small roots and bark have decayed; the nature of the soil, whether sand or clay, as this has to do with the resistance offered to the dynamite; the moisture content of the soil.

320. Blasting Taprooted Stumps.—There are two distinct methods of blasting taprooted stumps: (1) The charge may all be placed in a single hole bored into the root, or (2) it may be placed in one, two, or three holes alongside of the taproot. When two or more holes are used, electric firing must be practiced. Each method has its advantages. Placing the charge in the stump requires more labor and a smaller charge, while the other method requires but little labor and a greater amount of explosives. The first method reduces the stump and taproots to smaller fragments than the second. It should not be employed for stumps with decayed or hollow taproots.

Loading in the Taproot.—In order to place the charge in the root, a little soil is first removed with a spade, so that the taproot is exposed to a depth of a foot or more (Fig. 129). The hole is then bored diagonally downward through the center of the root. This hole should reach well below any possible depth of subsequent tillage and more than halfway through the root.

In loading, it is best to use a half-cartridge primer made with cap and fuse and to remove the rest of the charge from the paper shell. The charge should be packed firmly in the bottom of the hole, and the primer pressed close against it. The hole should then be tamped tight up to the very collar. Better results will be obtained if the loose earth is packed firmly back into the hole made to expose the taproot.

Loading around the Taproot.—In the second method of blasting taprooted stumps, the charges are placed around the root—between it and the soil (Fig. 130). Much depends on the depth and location of the bore holes. They should be not less than 3 feet deep, usually deeper, and placed close against the tap root, so that the charges will lie immediately along the side of the wood.

For blasting small or old stumps, only one hole is used, and the charge can be fired with cap and fuse. If the hole is dry, all the cartridges except the primer should be slit from end to end and packed tightly in the bottom. The primer should then be pressed firmly, and the hole well tamped.

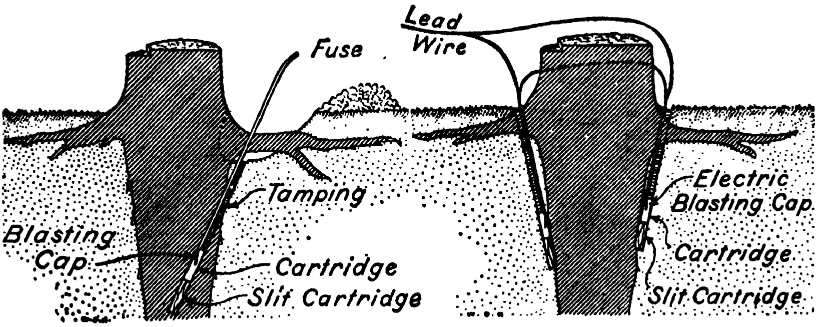

FIG. 129.—Location of bore hole and cap-and-fuse charge in a tap-root stump. In many cases the charge should be placed higher.

FIG. 130.—For blasting tap-root stump with distributed charges electrically fired.

321. Blasting Semitaprooted Stumps.—When stumps have a taproot of medium size and a heavy set of lateral roots, the loading will be intermediate between the loading for taprooted and lateral-rooted stumps. This loading is practically the same as that stated; the chief difference is that an occasional charge will be needed also under the heavier brace roots.

322. Blasting Large Lateral-rooted Stumps.—The use of distributed charges and electric blasting is essential to the best success in blasting large stumps having widespreading lateral roots. If the charge is confined in a single hole, the effect will be to split and not lift the stump, but if the same charge or even a smaller charge is distributed in several well-located holes, the blast fired by electricity will lift the stump out. The number and location of the holes must be governed absolutely by the individual stump. The holes should be placed around the outer edge so as to form a circle under and around the holding roots (see Figs. 131 and 132).

A stump with a solid top can often be shot better by springing a hole under it. To do this, place a third of a cartridge with a cap in it in the bottom of a bore hole with no tamping. When fired, a pocket is formed which is large enough to hold several pounds of dynamite concentrated at the end of the bore hole. After a sufficient time has been allowed for the hole to cool thoroughly, the charge is loaded with several cartridges, tamped, and fired in the regular manner. This is needed for lifting and splitting the heavy part.

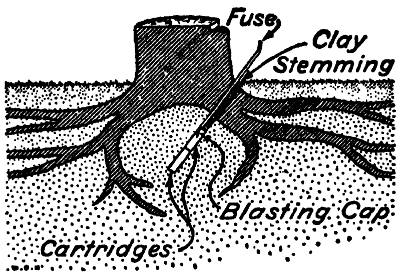

FIG. 131.—Incorrect method of loading a large lateral-root stump. Satisfactory for small stumps.

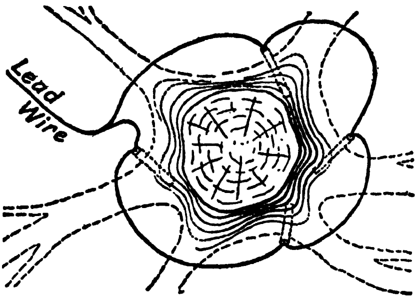

FIG. 132.—Correct method of loading distributed charges under and around a large lateral-root stump for an electrically fired blast.

As in all stump blasting, the holes should be well down in the subsoil—not close up to or in contact with the wood. The best tool for making the holes is the driving iron. Soil augers are sometimes used.

For cypress, willow, or other stumps in very soft, swampy soil, modification must be made in the usual methods of loading, on account of the poor resistance offered by the soil and the enormous number of spreading roots. The holes must be so distributed that not only the stump but also all of the main-spreading roots will be blown out below plowing depth. To insure the most efficient action of the explosives, the shots should be fired as soon as possible after placing.

323. Methods of Blasting Boulders.—There are four distinct methods of loading for breaking field boulders—block holing, snake holing, mud capping, and seam blasting. Block holing requires the smallest amount of explosives but the most labor, while mud capping requires the smallest amount of labor but a larger amount of explosives; snake holing is intermediate in both labor and amount of explosives required. Each method has its special use, as is pointed out in the following paragraphs.

324. Block Holing.—Block holing consists of drilling a hole into the boulder and charging it with a small amount of dynamite (Fig. 133). It is the best method for breaking very hard or very large boulders, especially those of the "nigger-head" type, that are so difficult to break by other methods. It is also effective in blasting outcropping ledges which are too large to remove entirely. The hole is usually drilled about halfway through the boulder and 1 inch or larger in diameter.

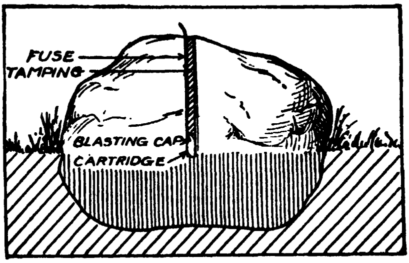

FIG. 133.—Properly placed block hole. Note location of explosive and blasting cap. Tight tamping is essential. (*Courtesy of E. I. du Pont de Nemours & Co.*)

When the hole is smaller than the diameter of the dynamite cartridge, the explosive is removed from the shell and packed firmly into the bottom of the hole. When the entire charge is in, make a hole for the cap in the top of the powder with a pointed hardwood stick. Press the cap into the hole and tamp it in full and tight with moist soil.

When the drill hole is large enough to receive the cartridges, they can be left in the paper shell, and a primer used for firing. For large holes, the cartridge shell should be slit several times from end to end.

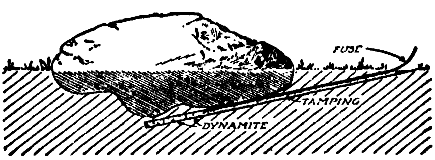

FIG. 134.—Correctly placed charge for a snake-hole blast. The charge should be in contact with the bottom of the boulder. (*Courtesy of E. I. du Pont de Nemours & Co.*)

325. Snake Holing.—Snakeholing consists of punching a hole under, and immediately against, the bottom of a boulder and placing the charge of explosives in a shape as compact as the size of the hole will permit (Fig. 134). The explosive, being confined on the underside by the earth, can exert a powerful blow on the boulder and will roll it out or, if a sufficient charge is used, will break it into fragments.

This is one of the easiest and most successful methods of boulder blasting. The best explosive for this work is 40 per cent dynamite. Many blasters prefer to lift boulders out with a snake-hole shot and later break them with a mud cap.

Sometimes, in the case of large boulders, a mud cap is used on the top of a boulder in connection with a snake-hole blast under it, and both charges are fired electrically.

326. Mud Capping.—Mud capping is known by a variety of fantastic and expressive names, such as "bulldozing," "blistering," "poulticing," and "adobe shooting" and is made possible by the fast, shattering action of the stronger and more quickly acting dynamite. In practice, it consists of removing the dynamite from the shell and packing it in a compact conical heap on the boulder and, after inserting a cap and fuse, covering it with the paper shell and several inches of thick, heavy mud (Fig. 135).

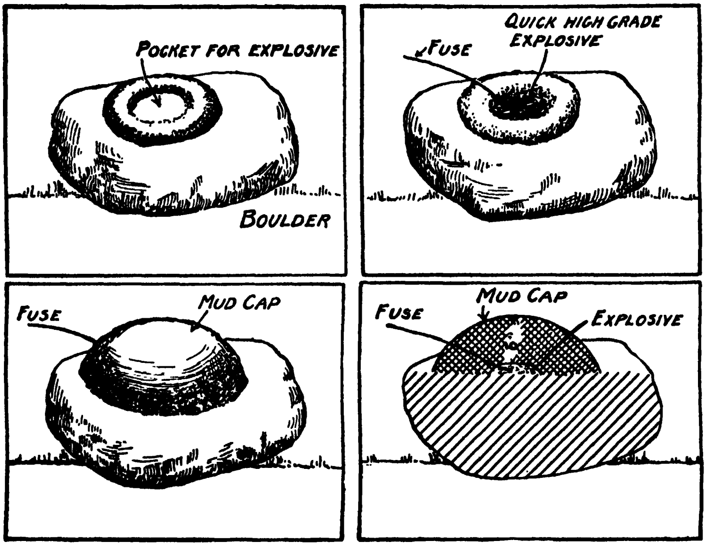

FIG. 135.—Mud capping. (*Univ. Wis. Agr. Ext. Circ.* 164.)

The explosive should be placed on the boulder at the place where it would be struck with a hammer were it small enough to be broken in that way. This may be on the top or side. If the boulder is embedded in the ground, a snake-hole shot should first be made, to roll it out on the surface, because the confining dirt makes it much harder to break with a mud-cap shot; or a trench should be dug around the boulder below the line of greatest girth. The mud covering should be as thick and heavy as it is convenient to make it—not less than 5 or 6 inches—and should be free from stones, as the blast will throw them as though they were bullets. For the same reason, a stone should never be laid on top of the mud.

327. Seam Blasting.—Frequently, ledges and boulders have seams from which the mud or stone chips can be removed to a considerable depth. When such a seam is as much as ½ inch wide, a successful blast can be made by packing a reasonable amount of 40 per cent or stronger dynamite into the crack and tamping it securely with moist clay. This method will require about the same amount of dynamite as snake holing but is more satisfactory for badly seamed boulders or ledges. The greatest care must be exercised in placing and tamping the charge, to prevent the expanding gases from escaping through the cracks.

328. Table of Charges for Blasting Boulders.—On account of the differences in hardness of rock in different places, and the variations in the shape of boulders in a single field, it is impossible to give exact information as to the quantity of explosive to use, but Table 24, which is based on stone of average hardness loaded with straight 50 per cent dynamite, will give some idea of the charges to use in making test shots. The recommendations are valuable only for making the first trial shots. After these are made, the blaster should be governed by the results obtained.

TABLE 24.—CHARGES FOR BLASTING BOULDERS

Diameter of boulder, feet	Number of cartridges required—50 per cent		
	Mud capping	Snake holing	Block holing
1½	2	1	¼
2	3	1	¼
3	4	1½	½
4	Do not attempt	4	¾
5	Do not attempt	6	1

This is based on the use of straight dynamite of 50 per cent strength. If extra 40 per cent dynamite is used, increase the amounts by half, and if farm powder is used for snake holing or block holing, double the amounts.

329. Blasting Ditches.—The use of dynamite is often of particular advantage in ditch work. It is adaptable to both large and small open ditches. It can be used in places where conditions make other methods almost impracticable. Very soft ground, large stones, stumps, and roots make ditching by hand or by machinery difficult. Ditches can be blasted in dry ground of a heavy nature, but, generally, the wetter the soil down to the thin muck stage the better and less costly the blasted ditch. It is not advisable to attempt blasting in dry sand or thin muck. In the case of ground where there are many roots, the sides of a blasted ditch will be ragged, unless the roots are cut along the sides beforehand; heavy sod land sometimes folds back without tearing loose or else flops back into the ditch, unless the ditch lines are cut before blasting.

FIG. 136.—Blasting a ditch. (*Courtesy of A. J. McAdams.*)

The use of dynamite is not advocated for ditches smaller than 1½ feet deep and 3½ feet wide. There are two distinct methods of blasting ditches—the propagation and the electric. In the former, a line of holes is put down and loaded, but only the central one is primed. When this is fired, the shock communicates itself through the soil water from charge to charge and fires each successive hole in the line. As only one hole in the line is fired by the blaster, the cap-and-fuse method may be used if precautions are taken to get them waterproof, as described; but the electric blasting cap is much safer and more satisfactory for this work. For ditching in soils of sufficient wetness so that when molded in the hand a film of water forms around the ball, the propagation method is the quickest and generally the most economical. It can also be practiced in the roughest of swamps where the ground is several inches under water, or where many stumps occupy the ground. Only a 50 per cent straight nitroglycerin dynamite should be used where the propagation method is relied upon, as other kinds are too insensitive to be detonated by the shock from a single primer in a central hole.

330. The propagation method is made possible by the fact that high explosives can be fired by shock. Under the conditions of soil described above and of proper loading the shock of the explosion of one charge will travel through the ground and water with enough force to fire the next charge, and so on to the next charge, and so on down the line. So rapidly does this take place that in a line of charges hundreds of feet long, one cannot see any difference in time between the middle and the end explosions.

The usual distance apart for charges to be fired best by the propagation method is as follows: When one stick in a hole is used, 16 to 20 inches; two sticks, 18 to 22 inches; three sticks, 24 inches; that is, when the temperature is 40° or more.

Careful observation of the blast resulting will show the proper spacing points, if it is remembered that the greatest distance that charges will propagate may not be the most economical. One charge may fire another at a distance greater than is economical to use, because it may merely cause the next charge to explode weakly, without developing anything like the full force and speed. And on top of that, each weaker explosion sends a still weaker one onto the next charge, till a point is reached a few charges away where the shock transmitted is not enough to bring about firing at all.

Ordinarily, in swamp soils, the holes can be put down with little effort. If the soil is hard or has a hard crust, a punch bar works well. If it is soft and mucky, a heavy tamping stick will suffice. The holes should be loaded at once, because, if left open, they cave in or become filled with floating slime; should the holes be made in advance of loading, some marker should be used to indicate where they are. After the entire line is loaded, the center hole should be charged with an extra primer cartridge.

In making this primer, care should be taken to waterproof both the joints between the cap and fuse and between fuse and cartridge with tallow, chewing gum, or paraffin. Tar and thin lubricating grease are very poor materials for waterproofing.

When water covers the charges, one should arrange to load and fire them quickly. A good plan is to make all the holes for one section, then prepare the charges as to priming and waterproofing, and distribute them along the line. Quickly test each hole for fallen stones or caved-in dirt, and push the charges to the bottoms of the holes. It is best to limit the period of soaking to ½ hour, as explosives are likely to be weakened if left in water too long.

If the holes cave badly soon after the bar is withdrawn, do not attempt to load and blast long sections at a time. In loose gravel and sand, especially where water covers the surface or nearly so, trouble will be experienced in pressing the charges down to the bottoms of the holes. Under these circumstances, the best plan is to use the ditching bar for sand and gravel, as previously described. This will allow the explosive to be loaded without difficulty.

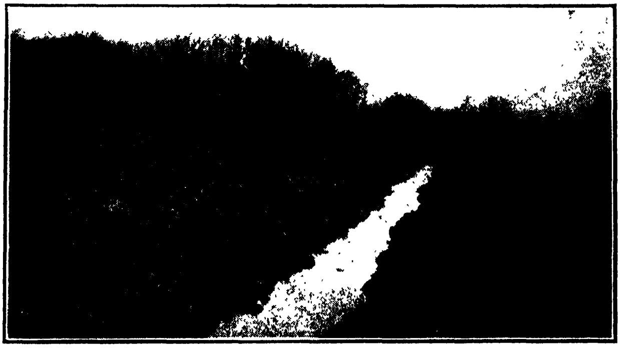

FIG. 137.—Small ditch excavated with explosives. (*Courtesy of A. J. McAdams.*)

Generally speaking, a ditch charge should be tamped. The more tamping that is done the broader the ditch will be in proportion to its depth. If a narrow ditch is wanted, the gases must be allowed to rip their way upward easily. In dry or damp soil, fill the hole about half full and tamp well. When water rises high in the hole, use no tamping at all except to tamp shut the upper 6 inches.

The ground should be warm for best results in ditch blasting. If it is cold, loading and firing the charges must be done quickly to prevent chilling of the explosive.

Regulating Depth and Width.—When conditions are normal, the soil will clean out 10 to 16 inches deeper than the bottom end of the single-stick charges and 6 to 10 inches deeper with the larger loads. A layer of hardpan or cemented gravel in the ground requires slightly deeper and heavier charges for removal than soft ground.

The greatest depth practicable to blast at one shot is between 4 and 6 feet. If a deeper ditch is wanted, blast a second time in the bottom of the first excavation. The blaster of very large ditches should consider the requirements, in order to make the second shot successful. One line or row of charges frequently will make a ditch up to 10 feet wide and 6 feet deep. To make wider ditches, use two or more rows. Usually, two rows of charges will be needed for ditches between 8 and 12 feet wide.

A. J. McAdams gives as follows his experience with the digging of ditches by use of explosives:

> The general rule which has been followed in the past is placing the charges to within 6 inches of the depth of ditch desired. Actual field work in Missouri indicated that this general rule is without foundation, and in place of an arbitrary depth of placing the charge, there should be applied a careful exact method of loading to a given depth in order that the most economical excavation may be secured. Many specialists have had experience in blasting a ditch 2½ to 3 feet deep and have found that a charge of one stick placed within 6 inches of the proposed depth will not do the work. The load above the cartridge is too great. Dynamite can do so much and no more. To expect one cartridge to move a load of 20 to 26 inches of wet dirt, leaving a clean excavation to the desired depth, is expecting too much of the explosive. Our field work in Missouri proves that charges placed 6 to 12 inches deep to the top of the last cartridge will more nearly give the required depth of ditch and a clean uniform excavation with the side slopes in much better condition and a wider top. In any case, where one cartridge is placed in a hole, there should not be more than 12 inches of soil over it. We have found in the heavier soils of Missouri that 6 to 8 inches depth to the top of the last cartridge will give the best results. In general, the heavier the soil the shallower the load should be placed. For a lighter soil, the charge can be placed somewhat deeper but not to exceed 12 inches.
>
> For deeper ditches, the depth to the top of the last cartridge should never be lower than 24 inches, and this depth is used only when a heavy charge of 3 or 4 pounds is forced in the bottom of the hole.

Practical field tests have proved that it is not entirely the upward force of the explosion which produces a ditch. This was shown by making a series of blasts with charges placed at different depths. These blasts indicated that it is the lateral force which makes the excavation, and the clearance to any given depth depends upon the character of the soil.

We found that modifications of depth loading prove conclusively that depth and clearance depend on the lateral force of dynamite exploded in the ground. To give a concrete example (Fig. 138), better clearance and greater depth are obtained with four 1¼ by 8 cartridges, if three sticks are loaded about 24 inches deep and one 1¼ by 8 stick to a depth of about 8 inches in a row 12 to 20 inches to one side of the three-stick row. This is what we call "relief loading" because the smaller charge relieves the overburden and permits the heavier charge to throw out a greater volume of dirt. This system of loading also provides for greater width than if all four sticks were placed in a single row of holes. Again, we proved that greater width and better depth are obtained if the heavier charge is placed in the center line of the proposed ditch with side rows of single sticks placed at a shallower depth.

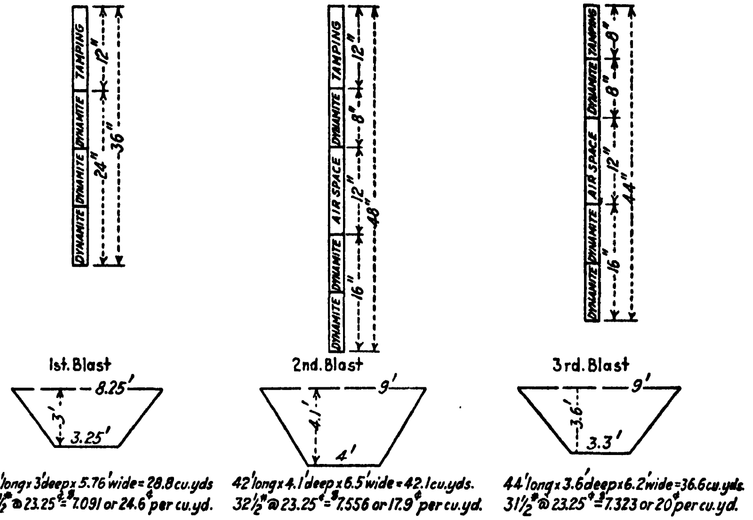
DYNAMITE
DYNAMITE
DYNAMITE
TAMPING
12"
24"
36"
1st. Blast
8.25'
3'
3.25'
45' long x 3' deep x 5.76' wide = 28.8 cu. yds
30½# @ 23.25¢ = $7.091 or 24.6¢ per cu. yd.
DYNAMITE
DYNAMITE
AIR SPACE
DYNAMITE
TAMPING
16"
12"
8"
12"
48"
2nd. Blast
9'
4.1'
4'
42' long x 4.1' deep x 6.5' wide = 42.1 cu. yds.
32½# @ 23.25¢ = $7.556 or 17.9¢ per cu. yd.
DYNAMITE
DYNAMITE
AIR SPACE
DYNAMITE
TAMPING
16"
12"
8"
8"
44"
3rd. Blast
9'
3.6'
3.3'
44' long x 3.6' deep x 6.2' wide = 36.6 cu. yds.
31½# @ 23.25¢ = $7.323 or 20¢ per cu. yd.

FIG. 138.—Method of loading and results to secure ditch of larger dimensions using same amount of explosive per hole—Biggs Farm, Columbia. (*Courtesy of A. J. McAdams.*)

Of late, we have had considerable interest in cleaning out old dredge ditches which have filled up. During the past year we have worked with six drainage districts on this problem, and so far dynamite can be used with considerable success for clean-out work. This will probably be of some interest to those who have drainage districts in their territory. The same general rule regarding depth of load is maintained. Instead of using the old system of loading in parallel rows lengthwise of the ditch, we have proved that "cross-section loading" produces a more uniform and cleaner job. Cross-section loading consists of rows across the ditch with the loads spaced to meet soil requirements. These rows are from 4 to 6 feet apart. They are connected with "connector" charges spaced at 16 to 20 inches apart. It is very important that these connector charges be spaced in a straight line parallel with the ditch. With this system of loading, the force of the explosion is lengthwise of the ditch, which permits the soil almost wholly to clear the spoil banks. In the old lengthwise system, the side slopes gave the soil direction with the result that the soil went straight up over the ditch and most of it dropped back. We believe the cross-section loading has solved this difficulty with practically no increase in amount of explosives.

For blasting ditches from 12 to 30 feet wide and 3 to 9 feet deep cross-section loading has been used with success. Where the ditch is more than 3 feet deep, one or two lifts may be needed to get the required depth.

331. Electrical Method.—For this method, the charges are prepared for loading with electric blasting caps in the manner already described. Prime each charge.

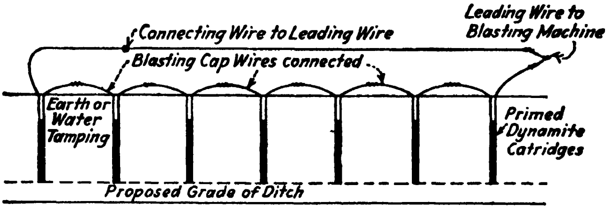
Leading Wire to Blasting Machine
Connecting Wire to Leading Wire
Blasting Cap Wires connected
Earth or Water Tamping
Primed Dynamite Catridges
Proposed Grade of Ditch

FIG. 139.—Longitudinal section, showing method of loading for blasting a ditch by the electric method.

The holes should be spaced 30 to 40 inches and, where very heavy charges are used, as much as 50 to 60 inches apart. They must be close enough together so that all the earth between each two will be thrown out cleanly, leaving no ridges in the bottom of the ditch. Thirty inches ought to be close enough for any

FIG. 140.—Explosive constructed ditch. (*Courtesy of A. J. McAdams.*)

condition of soil and size of charge. The only way of determining definitely just how far apart the charges should be is to make test shots as suggested. As many charges should be loaded as the electric current can fire (see Fig. 139).

The actual firing is done by connecting the wires of all the charges and sending an electric current through them. An electric blasting machine should be used to supply current. As many charges may be fired at one time as the blasting machine has capacity to handle. These machines are made in different sizes to fire from 30 to 150 charges at once. If miles of ditch are to be blasted, a large machine is needed, but if there are only a few hundred yards, a 30-charge machine is large enough.

As already mentioned elsewhere in this chapter, electric blasting caps will be needed for electric firing, in addition to the machine, and also connecting wire, possibly, and leading wire. The leading wire is made of copper and must be large enough to carry the full amount of current required for the number of charges to be fired simultaneously. It is covered with insulating material and is sufficiently strong and durable to withstand much hard usage. Two strands of leading wire are necessary to make the circuit from the blasting machine to and through the charges and back again.

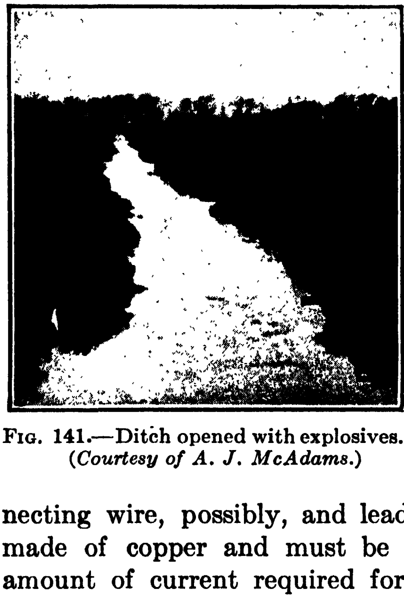

FIG. 141.—Ditch opened with explosives. (*Courtesy of A. J. McAdams.*)

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Univ. Wisconsin Extension Service, Circ. 164.

CHAPTER XX

LAND CLEARING[1]

It was pointed out, in Chap. I, that, in the aggregate, a vast area of land in the United States is withheld from cultivation and productive use because it is covered with brush, second-growth timber, fallen logs, and stumps. And, since economical clearing is a progressive, long-drawn-out process, many farms all over the country now contain cultivated fields in which stumps still remain. These stumps are a serious hindrance to cultivation, and they constitute a needless expense, probably adding as much as one-fourth to the cost of producing crops. They are also a positive menace to equipment. Fourteen plow points, costing $1 each, were recently found in a lightwood stump in Mississippi which was blasted out at a cost of 30 cents.

332. Economic Considerations.—So far as brush removal is concerned, experience has proved that the only way to clear land economically, under present conditions, is to do so on a small scale extending over several years and employing spare-time labor and equipment that would otherwise be idle. If the land is covered with brush, debris, and unmerchantable timber as well as stumps, the best time to begin clearing operations is during a period of agricultural depression, with cheap labor, so that when prices become normal the land will be ready to produce.

333. First Step in Preparation.—The first step in the preparation of cut-over land for cultivation is the removal of the fallen logs and brush. The fallen logs may be piled and burned, or they may be hauled off, while the undergrowth may be disposed of by grazing, cutting and burning, or plowing it under. The principal factor in determining which method should be used is the length of time the owner is willing to wait before putting the land in cultivation.

BRUSH

334. Grazing.—Grazing is theoretically an economical way to clear land of brush, and, undoubtedly, close grazing has a great effect in reducing the cost of removing the stumps at the end of the pasturing period.

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[1] Much of this chapter is a reproduction of parts of *U. S. Dept. Agr. Farmer's Bull.* 1526.

Goats, sheep, and cattle are the animals most frequently used for this purpose. Goats are natural browsers, and there is no vegetation that they will eat in preference to leaves and twigs, but, in practice, it has been found better to pasture cattle on the tract to eat up the grass (if it has been seeded) before turning goats into it. It is claimed that 100 Angora goats to each 40 acres of brush land will make the land as clean and grassy as a lawn in two years, but some authorities say that 160 to 200 head of goats to 40 acres is not too many. Sheep are the next best browsers but must be more closely pastured than goats in order to force them to eat the bushes. In the cut-over lands of the Upper Peninsula of Michigan, one ewe and one lamb will thrive on 1 acre of cut-over land during the open months and will keep down all the sprouts except conifers.

With either sheep or goats, on large areas, it is necessary to fence the land into small sections, concentrating the animals on each section for a short time until it has been browsed clean, then moving them to another section, then back to the first one, and so on.

Where grazing is depended upon to remove the underbrush, it is usually necessary to cut such of the brush as is too high for the animals to reach. Such work should be done as early in the stage of the operation as possible. The cut brush and trees may be piled with the fallen logs and burned, or they may be left to decay, but when this is done they should be left as they fall and not piled up, as the brush in piles generally does not rot so readily as when scattered on the ground. A growth of grass aids greatly in keeping down the suckers and sprouts and hastens the decay of fallen brush but affords more feed for the stock so that the brush is not eaten so quickly. It is advisable to go over the land at frequent intervals and cut down the growth which may have been avoided or neglected by the stock in grazing.

335. Cutting and Burning.—The most common method of brush disposal is to cut, pile, and burn it. This method gets rid of the brush quickly so that it will not interfere with the immediate cultivation of the land. Down logs, dead tops, and unmerchantable timber are worked up and removed or piled and burned as a part of the brushing operation.

The general impression seems to be that brush cut in the summer or early fall is not apt to sprout again, but investigations have demonstrated that there will always be some second, and even third, growth, regardless of when the brush is cut. To insure killing the growth, it is necessary, generally, to go over the field at intervals and cut down the new growth. A great deal of brush is cut in the winter, because other farm work is not so pressing at that time and more labor is available.

The tools needed are few, but they should be in good working order. An axe and a brush scythe or brush hook are about all that are needed for cutting the brush. For handling the logs, a team, a chain about 15 feet long, a 30-foot length of ½-inch cable, and a crosscut saw are required.

FIG. 142.—A log pile should be compact and narrow, with the logs lying parallel, and should be of good height.

The best piles of brush and logs are high and rather narrow, as shown in Fig. 142. Piling in small piles, fairly high, with the logs lying parallel is cheaper and better than making large piles, since the latter require additional labor, and, if the pile is too large, the fire may become so intense as to injure the fertility of the underlying soil. Logs and stumps should be burned in separate piles, as much more compact piles can be made in this way. In piling logs which cannot be readily handled, a team, cable, and two timber skids may be used to advantage. The pile is started by passing a cable end under the log to be moved and hooking it to the log which is to be the center piece of the pile. The team, hitched to the other end of the cable, rolls the log up to the pile by means of this *rolling hitch.* It is good practice to put two or more crosspieces under log piles to provide air circulation when the pile is drying out and a draft when it is burning. Sometimes, the brush is piled in windrows, which saves moving it through any considerable distance, but the windrows do not always burn up completely. Such windrows should extend in the direction of the prevailing wind in order to get a good burn. Very large logs are most easily burned in place after splitting their ends with explosives.

As a rule, standing trees should be cut down before the brush is cut. It is generally better, especially where the trees are thick, to cut the trees and later remove the stump than it is to remove both tree and stump in one operation. While it is somewhat easier to pull a tree with a stump puller than it is to pull the green stump, on account of the greater leverage which may be obtained by fastening the pulling cable higher on the tree than is possible on the stump, and, while it takes but little more explosive to blast a tree than a green stump, in thick woods the fallen trees occupy so much ground space as greatly to increase the difficulty and cost of the operation.

FIG. 143.—An Eastern North Carolina field where the growth has been cut down and burned. The first crop of corn has just been planted.

336. Plowing.—In some places where the stumps are few and far apart, it is possible to plow the brush under and immediately put the land in crop. All trees over 2 or 3 inches in diameter or more than 6 to 8 feet high should be cut down, and all stumps more than 6 inches in diameter should be removed before plowing is attempted.

337. Kinds of Plows and Tractors.—A great variety of kinds and sizes of plows is being used for this work, depending, in part, on the growth and the soil and, in part, on the owner's opinion of the results secured with the various makes of plows. Tractors are used for motive power, because, although it would be possible to hitch enough horses to the plow to pull it, they would not be so effective in breaking down the brush and small trees as is the tractor. The size of the tractor required depends on the power it will be called upon to furnish. For heavy brush, the tractor should have plenty of power, the driving wheels should be equipped with extension rims and strong lugs, and it should have a large bottom clearance in order to pass readily over small stumps, débris, and stones. Some operators prefer to hitch the tractor to the plow with a chain about 10 feet long to give the plow greater flexibility, while others prefer a rigid, but adjustable, attachment so that the plow can be backed up when it gets wedged under a stump. The plows and coulters are of many different designs, but a single bottom plow, from 20 to 24 inches wide, with a landside about 5½ feet long and 6 inches in width for large plows, and some form of standing coulter, seems to be the most popular. It is important that there be from 20 to 26 inches of clearance at the throat of a plow so that it will not be necessary to stop too frequently to clear the plow of brush and débris.

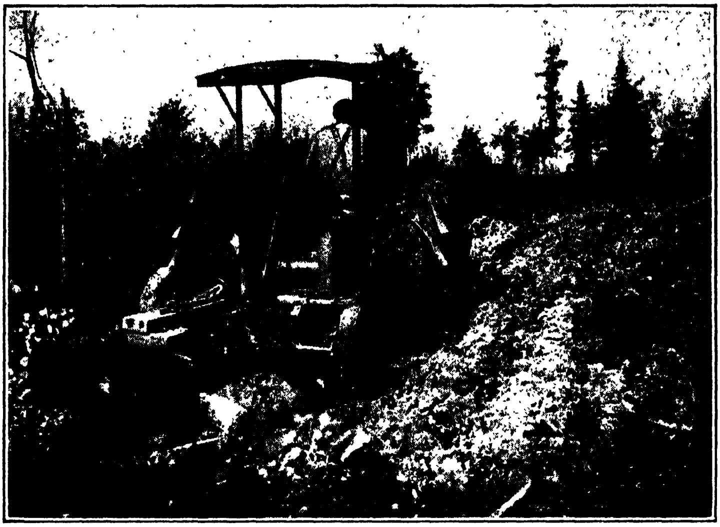

FIG. 144.—Brush plow developed by the Agricultural Engineering Department of the University of Wisconsin. The plowshare is offset 8 inches to the right of the beam to prevent choking.

338. Wisconsin Plow.—The Department of Agricultural Engineering of the University of Wisconsin has developed a brush plow with a throat clearance of 26 inches, which also has an offset in its beam so that the plow bottom is some 8 inches on the right side of the beam. This permits the space directly in front of and above the plow to remain relatively free so that most of the brush is caught and turned under by the rolling action of the furrow slice. A standing cutter, the upper end of which curves backward and to the right, was also designed further to prevent choking. This plow is shown in Fig. 144.

339. Minnesota Practice.—A compilation of returns to a questionnaire sent out to Minnesota farmers gives the following information as to the equipment used for plowing underbrush in that state.[1]

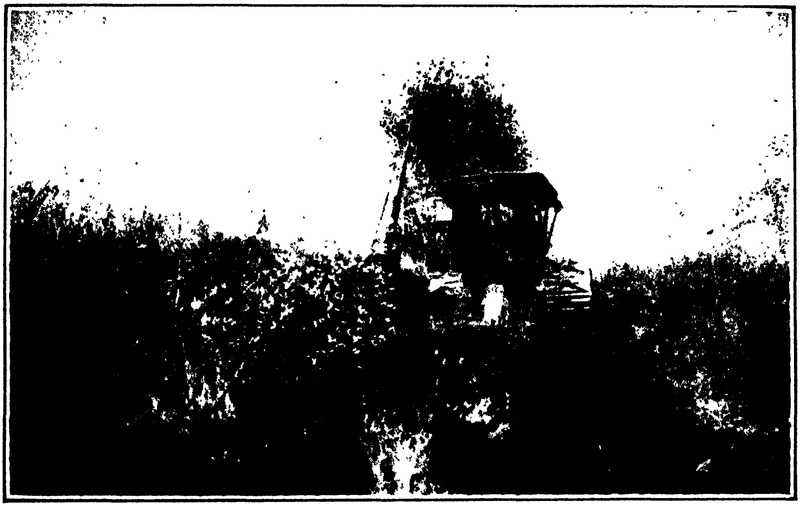

FIG. 145.—Plowing brush on drained swamp land in Minnesota.

Average drawbar power of tractors, horsepower		15.25
Average size of cut, inches		27.50
Average depth of breaking, inches		6.30
Average clearance of plow, inches		21.00
Average operating cost per 10-hour day:		
Gasoline or kerosene	$5.27	
Oil and grease	1.39	
Labor, 40 cents per hour	9.00	
Total		$15.66
Average cost per acre		4.24

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[1] "Investigations in Stump and Stone Removal," *Univ. Minnesota Dept. Agr. Eng. Bull.* 208.

The same report also says that the best time for plowing underbrush is in June, July, and, possibly, August; that where brush has been plowed under, the land can be plowed a second time within 2 or 3 years after the first breaking; that more satisfactory work can be done when the ground is comparatively dry than when it is very wet; that, after plowing, the field is usually disced and sown to flax, hay, or grain; and that crops grown for the first 2 years may equal those raised under normal methods of cultivation, if all conditions are favorable.

340. Handling Palmetto.—In parts of several Southern states, the scrub or saw palmetto is the principal undergrowth. This plant has a strong horizontal root which grows along or under the surface of the ground, and from this root an immense number of vertical feeder roots extend down into the soil. Formerly, the palmetto was grubbed out by hand at a cost of from $75 to $150 per acre, but usually it can be plowed under with a heavy breaking plow. When the horizontal roots are more than 3 inches in diameter and are present in considerable numbers, it is almost impossible to turn them under with the ordinary plow. A plow used with some success for this purpose has a vertical cutting edge like a heavy standing coulter beneath the beam. At its lower end, about 4 inches below the ground, there are two horizontal knives, 18 inches long, extending at an angle of 45° in both directions. After this plow has cut off the feeder roots, the palmetto can easily be pulled by hand and thrown into wagons to be hauled off and burned. With a small tractor, about 2 acres of palmettos can be cut off in a day, and, with a large tractor, about 3 acres can be done in the same time. The manufacturers claim that heavy palmetto land can be cleared by means of this plow for about $20 per acre.

STUMPS

341. Grubbing.—The earliest and most primitive method of stump removal, that of hand grubbing, is still used extensively, in spite of the fact that it is very hard and tedious work. It is such laborious work that men cannot be hired for this purpose so long as other and easier jobs are to be had. For small stumps, up to 6 or 8 inches in diameter, it is generally the most effective and economical method of removal. As the size of the stump increases, however, the economy of this method tends to decrease, but even on large stumps, where labor is cheap, the costs are not excessive. A South Carolina planter says that, during the winter of 1921–1922, he paid out over $400 for grubbing stumps at a cost of 10 cents per stump but that, 2 years earlier, he could not have contracted this work for $2 per stump, as men would not do such work at any price during prosperous times. In the summer of 1922, the contract price for grubbing stumps in the Mississippi Delta was 25 cents per stump. In southern Texas, labor is, or has been, so plentiful that grubbing out mesquite has been generally contracted for at a price of $15 per acre.

The tools required for grubbing are an axe, a grub hoe or mattock, and a shovel.

342. Advantages and Disadvantages of Grubbing.—The advantages of grubbing out stumps are that (1) it requires no investment in tools or equipment, (2) it can be used equally well on thick or scattered, green or dead, rotten or solid stumps, and (3) it makes a clean job of removing the roots. The disadvantages are that (1) it is very slow and laborious, (2) for large numbers of stumps it requires either a large number of men or a long time, (3) it leaves the stump and roots in such shape that the large ones are hard to handle and dispose of, and (4) where labor has to be hired at high rates, it is quite expensive. Large numbers of stumps are being removed by farm labor

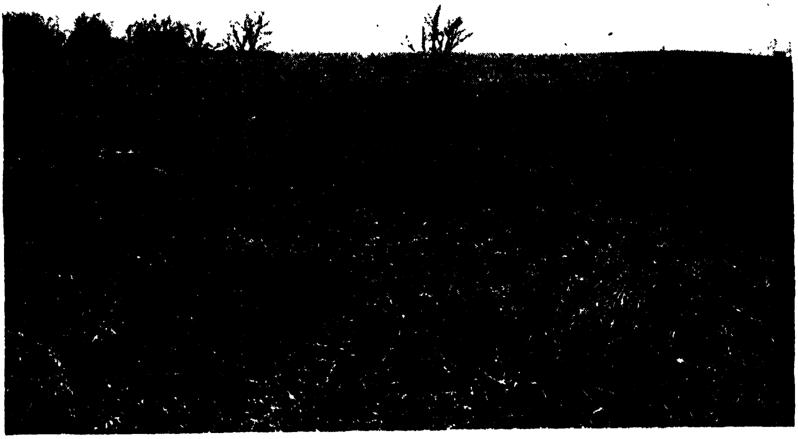

FIG. 146.—Scattered stumps are keeping this fertile, Iowa field from producing cultivated crops.

during intervals when there is no other profitable farm work to be done, and, under such conditions, the grubbing method should receive careful consideration.

343. Burning.—Fire, one of the oldest methods of destroying stumps, is still used to good advantage under many conditions. While it is a comparatively simple matter to build around a stump a fire which will consume it, it is extremely difficult to burn the stump roots to a depth where they will not interfere with the cultivation of the field. The usual minimum depth required, so as to be beyond any probable plowing depth, is 18 inches, since the ground around the stump is generally higher than the general surface and because there will be considerable settlement in the ground when the stump is removed.

To secure a good fire, the amount of heat present should be confined and conserved as much as possible, and the air supply should be limited to just what is required for combustion.

344. Methods of Burning.—Stumps are burned with free or open draft, by char-pitting, and by devices for securing forced draft. Occasionally, it is possible to build on the outside of a stump a fire which will burn so readily as to destroy most of the roots, but usually it is necessary to get the fire into the center of the stump, where little heat will be lost by radiation, in order to burn the roots. With the taprooted pine stumps of the South, which seldom exceed 30 inches in diameter, the general method of burning is to dig a hole, 13 to 15 inches deep and about 1 foot wide, on one side of the stump, down along the taproot, and then to bore a hole from the surface of the ground on the other side of the stump into the bottom of the dug hole. This hole should be about 2 inches in diameter, for smaller holes sometimes become choked with soot. A fire is started with chips or brush in the bottom of the dug hole, and, as the draft through the bored hole draws the fire into the stump, the whole stump will soon be blazing. A small amount of brush may be piled around the burning stump to increase the draft and heat, but if too much brush is used it will keep the air away from the fire and the outside of the stump will become charred so that it will not burn completely. It is best to have only a small fire and to keep it going by frequent attention. It takes from 24 to 36 hours to burn a dry stump, and one man can keep about 75 stumps burning if they are not too widely scattered. Some burners watch their fires throughout the night, but if only a few stumps are to be burned and the fires are started early in the morning, only one rebuilding should be required. Both stumps and ground must be dry to secure good results, so this work can be done only when the weather conditions are right. A heavy rain may put out the fires, and when this occurs they are very hard to start again.

When this method is used on the large stumps of the West, two or more holes are bored into the stump. One hole is bored down the center of the stump to a depth of 1 foot below the ground surface, and a second hole, started at or below the ground level and piercing one of the large roots, is bored so as to intersect the first hole near its lower end. The fire is started with a hot iron, a glowing coal, or a blowtorch at the junction of the two holes. A hand bellows is very useful in getting a blaze started.

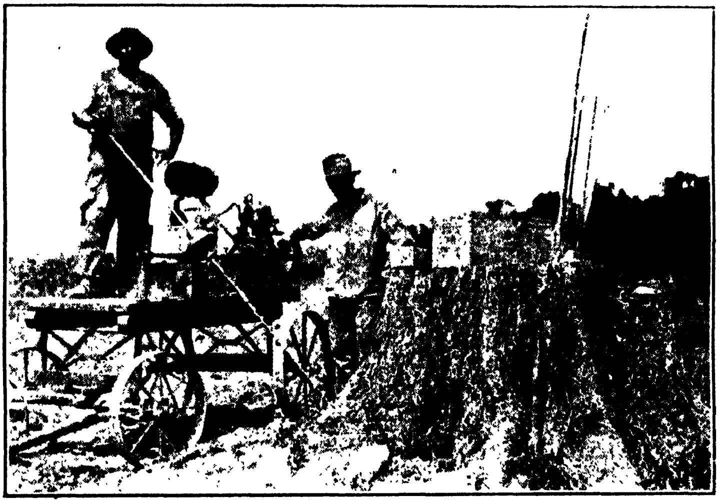

Fig. 147.—Gasoline engine-driven auger used for boring holes in stumps to facilitate burning.

345. Pulling.—There are many mechanical devices for the use of power in pulling stumps, ranging from the straight pull of a team to huge machines with immense pulling power.

346. Low-power Pullers.—The simplest puller is a chain with a hook on one end and a team of horses on the other. The hook is fastened to, or around, one of the main roots of the stump and placed across the top of the stump, which acts as a fulcrum, thus giving a leverage which increases the pulling power of the team. Stumps of considerable size can be pulled in this way if sufficient grubbing and chopping off of roots be done to lighten the pull required until it comes within the capacity of the team. The pulling power of a tractor can be used in the same way, and somewhat larger stumps can be pulled than can be moved with a team. Such work is hard on either team or tractor, and it is generally better to increase the power available than to attempt to pull large stumps with such a simple outfit. This can be done by using a longer chain, a rope, or a wire cable in place of the short chain and threading it through one or more pulleys or blocks. A wire cable about ⅝ inch in diameter is the best, for a rope is usually too weak to stand the continued strain, while a chain is heavy and unwieldy. By using one pulley, the power can be doubled, and two pulleys will treble the power, but the time required to pull the stump is increased, and it also takes more time to attach and fasten the cables and get ready to pull.

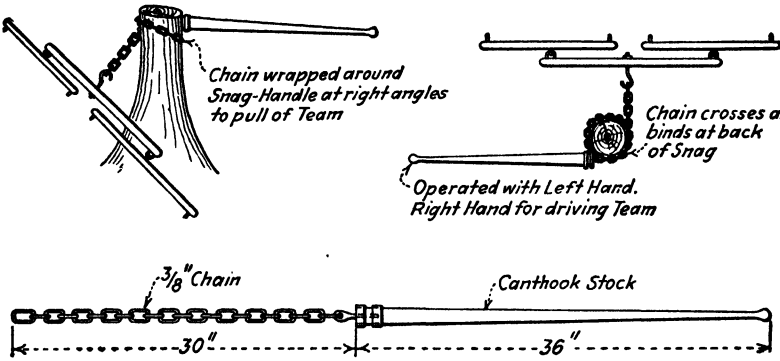
Chain wrapped around Snag-Handle at right angles to pull of Team
Chain crosses and binds at back of Snag
Operated with Left Hand. Right Hand for driving Team
3/8" Chain
Canthook Stock
30"
36"

FIG. 148.—The chain whip.

347. Twisting Device.—A simple device, called a *twister*, is used with fair success in some localities. It is a pole beam about 20 feet long of some tough wood, with a chain and hook on one end. The chain is wrapped around the stump and made fast with the hook, and a team, fastened to the free end of the beam, walks around the stump thus twisting it until the roots pull out or are broken off.

348. Whip.—A device called a *whip*, illustrated in Fig. 148, has been developed by the Agricultural Engineering Department of the Michigan Agricultural College, for pulling brush, snags, and small stumps. It consists of a cant-hook handle, to the large end of which a ⅜-inch chain, 2½ feet long, has been fastened. The free end of the chain is fastened to the whippletrees of a team; the operator wraps the chain around the stump so that it is crossed and binds on the side away from the team, and, holding the end of the cant hook in his left hand so as to keep the chain rigidly in place, he drives the team ahead with the reins in his right hand. As soon as the stump is pulled, the chain can be readily disengaged. On small stumps and standing brush, this device works very rapidly and efficiently.

349. Mallet Puller.—For somewhat larger stumps, a *mallet stump puller*, shown in Fig. 149, can be cheaply made with the tools available on any farm. This large mallet has a head of cedar, or other light wood, 18 inches in diameter and 30 inches long, while the handle is of hickory, or other tough wood, about 6 inches in diameter and 6 feet long. A pull chain, 12 feet long, is fastened to the end of the handle. It is operated by placing the head of the mallet as close to the stump as possible, with the handle in an upright position against the stump. A heavy chain with a *corner-bind* or *fid-hook* attachment is placed around the stump as low as possible and then around the handle where it enters the log; it is essential that this chain be as tight as possible, as the greatest leverage is obtained when there is no slack. When the handle is pulled down by the team to a horizontal position, the stump is turned up on the mallet head. The pulling power of the team is increased about six times with this device. Very little strain comes on the mallet head, so the lightest obtainable wood should be used for it, but the handle should be made of tough, strong wood. The 6-inch hole can be made in the mallet head by cutting or burning, but the best way is to bore several small holes within the area of the proposed

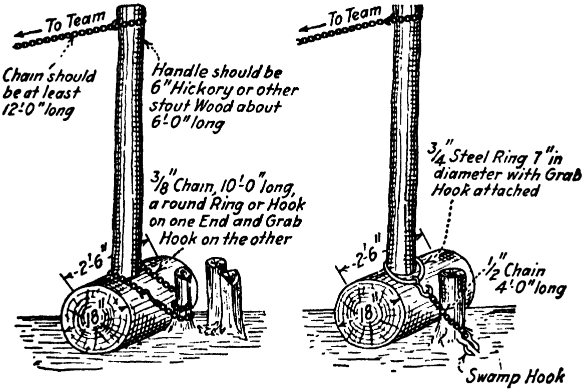
To Team
Chain should be at least 12'-0" long
Handle should be 6" Hickory or other stout Wood about 6'-0" long
3/8" Chain, 10'-0" long, a round Ring or Hook on one End and Grab Hook on the other
2'-6"
18"
To Team
3/4" Steel Ring 7" in diameter with Grab Hook attached
2'-6"
1/2" Chain 4'-0" long
18"
Swamp Hook

FIG. 149.—Mallet stump puller (Paul Bunyan hammer).

hole and then, with a chisel, to chip out the walls between the small holes. An iron bolt through the mallet head, to keep the handle from coming out, an eyebolt at the top of the handle, and some sheet metal at the lower end of the handle, to prevent the chain from wearing into it, are all good additions but are not essential.

350. Requisites of a Good Stump Puller.—There are a number of types of manufactured or commercial stump pullers, differing in design, in the source of the motive power, and in size. The primary requisites of all types are (1) enough power must be developed to do the required work; (2) each machine must be so constructed that it can be operated with safety; and (3) it must be capable of being moved about easily, or it must be equipped to pull a large number of stumps from one place.

351. Method of Operation.—All these pullers, except the large machines, must be anchored to a substantial stump. Practically all of the small machines have an anchor cable which is placed around the anchor stump and allows the puller to swing around with the direction of the *pull line*, thus permitting the pulling of all the stumps within reach of the pull line from one anchor stump. The pull line is fastened to the stump which is to be pulled with a *choker hook*. There are several kinds of devices, called *take-ups*, equipped with a short cable and choker hook, which can be attached to the pull line at any point for pulling stumps close to the machine or for pulling more than one stump at a time. There are *cluster cables*, which can be attached to the end of the pull line for pulling a group of stumps with one pull. Pulleys, to which are attached short cables with choker hooks for anchoring, can be introduced to increase the power of the pull. *Root hooks* are made for pulling roots, snags, or stumps which have been cut too low to allow the pull line to be fastened to them. Figure 150 shows a type of root hook which has been used with much success in Michigan. Most pullers are arranged for two speeds. The slow speed, having the most power, is used for heavy pulling, while the high speed is used for pulling small stumps and dragging the pulled stumps to a pile. With some designs, the speed may be changed while the pull is being made if desired. Safety is obtained by various automatic locking devices which reduce the liability of accident in case any part breaks.

The economical operation of a stump puller and its accessories is a matter that requires both experience and judgment. Efficient operation requires speed, and that means that the operator must be able to plan his work ahead and use his equipment so that, as soon as the strain is taken off by one stump's coming out of the ground, it is taken up by another stump. It is largely because of the many niceties of adjustment in the use of accessories and the ability to know precisely in what order to pull the stumps, that one crew will pull twice as many stumps in a day as another.

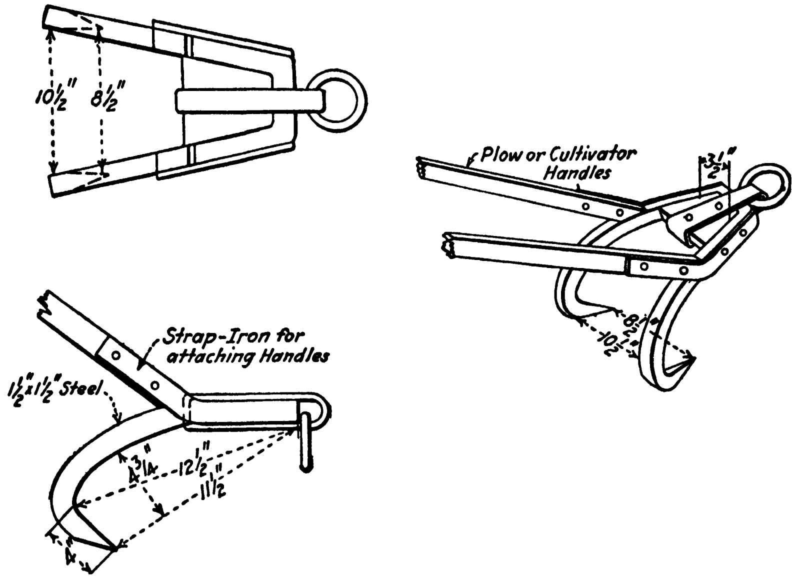

FIG. 150.—Root hook. (*Agr. Eng. Dept., Michigan Agr. College.*)

FIG. 151.—Pulling stumps with horsepower puller.

The motive power of the pullers may be hand power, horsepower, or power taken off tractors or from steam or internal-combustion engines.

FIG. 152.—Stump-pulling attachment for tractor.

352. Blasting.—Explosives are widely used for blasting stumps entirely out of the ground, for loosening up large stumps before pulling, and for splitting stumps which have been pulled. The details of stump blasting and the use of explosives for this purpose are described in Chap. XIX.

353. Decay.—In some sections, the stumps are left in the cultivated fields until they become so rotten that they can be knocked over with an axe. A number of stumps, such as the oaks, ash, hickory, and gum, will rot so that they can be easily removed in from 5 to 10 years; but there are others, notably the pine, fir, cypress, poplar, and cedar, which will not decay to an appreciable extent for many years.

354. Use of Poison.—In some sections, the process of decay of the stump is hastened by poisoning the tree while it is still living. Around the trunk of the tree are cut gashes into which a solution of arsenic is poured. The leaves all die within a week or two, and decay sets in soon and works rapidly in both tree and roots. In 4 months, worms will be found working in the wood; in 2 years, most of the branches fall; in 4 years, the trunk is gone; and the stump can be easily removed in about 6 years. Each of the following mixtures has been successfully used.

Formula 1	
White powdered arsenic	1 pound
Washing soda (sal soda)	3 pounds
Water	4 gallons
Whiting	1 pound

Formula 2	
White powdered arsenic	1 pound
Caustic soda	2 pounds
Water	4 gallons
Whiting	1 pound

The soda should be dissolved in water, and the arsenic made into a paste before combining these chemicals. The procedure is as follows:

1. The soda should be completely dissolved; if washing (sal) soda is used, 1 or 2 gallons of water are brought to the boiling point, and the soda added a little at a time, stirring constantly. Caustic soda does not require that the water be hot to bring it into solution.

2. The arsenic paste should be made by adding, a little at a time, the dry, powdered arsenic to the required quantity of water. Care should be taken not to breathe the arsenic dust, as it is poisonous.

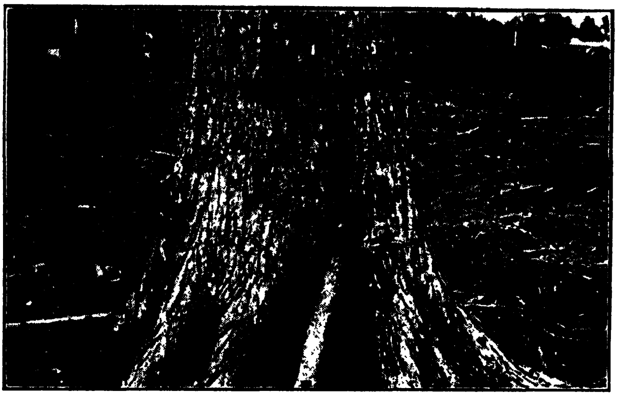

FIG. 153.—Gashes are cut entirely around the trunk of the tree to receive poison which hastens decay.

3. The arsenic paste should then be added very slowly to the soda solution, stirring constantly and taking care to stand away from the poisonous fumes.

4. When both the arsenic paste and the soda are dissolved and chemically combined, which requires from 20 to 40 minutes and can be determined by the mixture's becoming clear, add the balance of the 4 gallons of water and then the whiting. The whiting serves as an indicator on the trees treated, as it turns white on drying and thus shows which trees have been poisoned.

To apply the preparation, cut around the trunk of the tree a continuous row of shallow gashes penetrating into the sapwood, as in Fig. 153. Make the cuts so that they will retain the poison instead of permitting it to run down the outside of the trunk. Pour the solution into the cuts, using an old teakettle or coffeepot with a long spout for convenience in applying. Since the whiting has a tendency to settle to the bottom, the mixture should be constantly shaken while pouring.

There are many diverse opinions as to the best time of year for poisoning. Some say in the spring when the sap is rising or in the summer while the sap is up in the tree; others claim that the best results, especially as to killing sprouts and suckers, will be secured by applying the poison in the winter when the tree is dormant. The species of trees which are said to be most susceptible to poison are the hardwoods, including elms, maples, locusts, and ash. Gums, persimmons, hickories, cottonwoods, and pines are less susceptible. It is advisable to keep stock out of a field for several days after the poison has been applied.

The compound will keep indefinitely in an airtight container and for some time in an open vessel. It should never be left where children or stock can get at it, and vessels which have contained poison should be destroyed.

The quantity of the solution to use depends upon the size of the tree. For trees 4 feet in diameter, about 1 quart of the poison is said to be required.

Whatever success may be had in hastening the decay of trees by the use of poison is due to the fact that the poison is introduced into the circulatory sap system of the tree and by it is distributed to every part of branch and root. As neither green suckered nor dead stumps have a general circulatory sap system, the use of poison on stumps has no appreciable effect upon their rate of decay. It is, however, possible to kill suckers by cutting them off and applying poison to the freshly cut stubs. No effect in hastening decay or in facilitating burning can be obtained by introducing chemicals, such as saltpeter, sulphuric or nitric acid, or mixtures of these acids, into a stump.

The advantage of leaving the stump or tree in the field until it decays completely is that it decreases the first cost of the land-clearing operation. The disadvantage is that the presence of the stump or tree in a cultivated field during the time required for it to decay so decreases the amount of land available for crop and so increases the cost of cultivation that the first saving is usually more than counterbalanced. Where there is no money available for removing them, it is better to poison the trees than to allow them to continue to grow, as the time required for decay is somewhat shortened by poisoning.

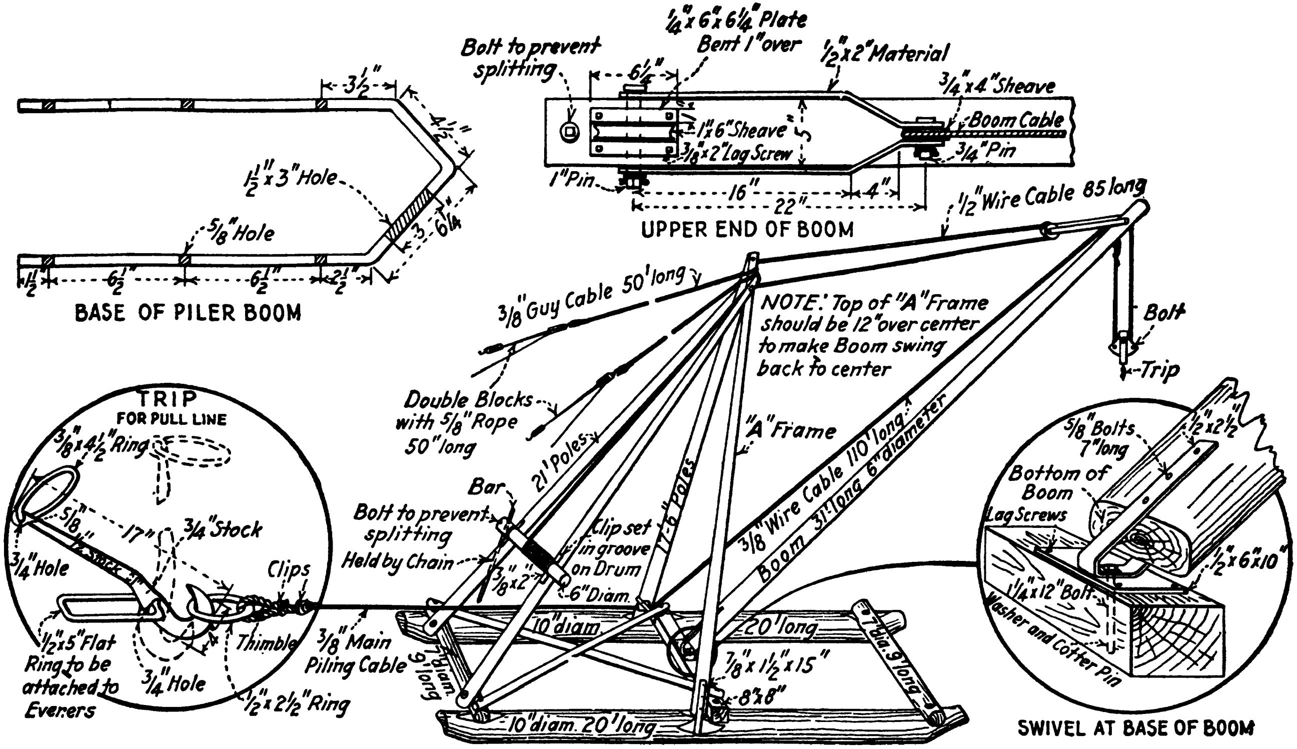

FIG. 154.—Conrath stump piler. (*Univ. of Wis. Agr. Exp. Sta. Bull.* 320.)

355. Disposal of the Stump.—Not the least of the problems in clearing land is the disposal of the stump after it has been removed from the ground. Experience shows that it usually costs about as much in time and money to destroy the stump as it does to pull or blast it. Unless the stump can be removed from the field, it is better to leave it in the ground than on top of it.

The usual method of stump disposal is to pile and burn, an operation which is not so simple as it sounds. It is first necessary to gather the stumps into piles, and, where the stumps are small or have been well broken up by blasting, this is usually done by dragging the pieces to the pile with a team. A small pile is started by rolling and skidding a number of stumps together, and when the pile gets too high to roll them onto it by hand, a long chain is thrown over the pile and the stumps are hitched so as to roll them up onto the pile when a team pulls on the chain. A tractor may be used in place of the team for dragging and piling the stumps. More elaborate means may be necessary where the stumps are large and numerous, and lines drawn in by any of the various types of hoisting engines may be used for this purpose. The stumps may be lifted onto the pile by a cable threaded through a block at the top of a tree, gin pole, or portable derrick. Generally, some form of gin pole is used, on account of its cheapness and ease of handling. The Conrath piler (Fig. 154), which

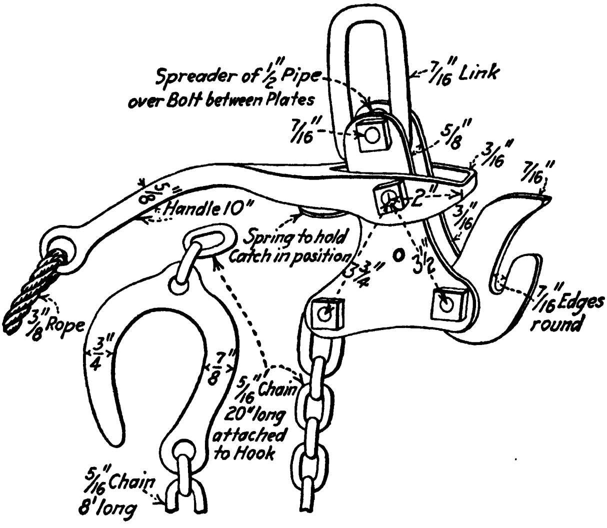
Spreader of 1/2" Pipe over Bolt between Plates
7/16" Link
7/16"
5/8"
3/16"
7/16"
5/8"
Handle 10"
2"
3/16"
Spring to hold Catch in position
3/4"
3 1/2"
7/16" Edges round
3/8" Rope
3/4"
7/8"
5/16" Chain 20" long attached to Hook
5/16" Chain 8' long

FIG. 155.—The Frost trip. (*Univ. of Wis. Agr. Exp. Sta. Bull.* 320.)

has been used extensively in Wisconsin, requires very little blacksmithing and can be built quite cheaply. With any device for lifting stumps into a pile, some kind of trip to release the stump at the proper time is desirable. The Frost trip (Fig. 155), also developed in Wisconsin, gives very good satisfaction and can be cheaply made by a blacksmith.

356. Selection of Most Appropriate Method of Clearing Land. Undoubtedly, the most important factor in the determination of method is the fact that many of the farmers all over the country are without funds to invest in equipment for stump removal. To a man in this position, it is immaterial how cheap may be a method which requires a heavy investment, as he, perforce, must use some method which comes within his means. In such a case, grubbing, the use of homemade pulling devices, burning, and blasting are the only available methods. (Blasting is included in this list although it does require the investment of some money, for a man may very well be able to buy 100 pounds of dynamite for use on the large stumps, where he would be entirely unable to buy a stump puller.) A man in this situation would use grubbing, for this is the cheapest method of getting small stumps out, especially where slack-time labor is used, and as the size of the stumps increases, he will use his team or tractor and the homemade pullers in pulling, and with the very large stumps he will use explosives to split or blast them out entirely. He will use the burning method only for resinous stumps, in clay soils, and where labor is sufficiently careful and painstaking to insure the destruction of the roots.

The choice of methods for the removal of scattered stumps, either in cut-over areas or in cultivated fields, is limited generally to grubbing, pulling with teams, tractors, or light pullers, burning, or blasting, for the reason that so much time is lost in moving heavy equipment among widely scattered stumps that their operation is not economical.

The man who has only a small number of stumps to remove cannot afford to invest heavily in equipment, so he, too, must choose among grub hoe, mallet puller, fire, and explosives.

There are doubtless many localities where types of the power pullers can be rented for a nominal sum, and, in such localities, the use of the horsepower puller and heavier equipment might be advisable, where the amount of the work would not justify their purchase.

Where large areas are to be cleared, all the methods and equipment reviewed in this chapter, as well as other heavy machinery which has not been described on account of its limited use, may be employed. The selection of the method, in this case, should be made only after a careful balancing of a large investment and heavy operating costs with a large daily output, on the one hand, against a small investment, small operating costs, and small areas cleared daily, on the other.

References

U. S. Dept. Agr. Farmers' Bull. 1526.
Univ. Wis. Agr. Expt. Sta. Bull. 320.
Univ. Minn. Agr. Expt. Sta. Bull. 134, 189, 208.
Miss. Agr. Expt. Sta. Bull. 159.
Univ. Idaho Agr. Expt. Sta. Bull. 91.

CHAPTER XXI

CONTROL OF SOIL EROSION

True conservation has been defined as "utilization of resources without waste." It has already been shown that uncontrolled erosion due to the action of surface water has resulted in enormous wastage of topsoil from a majority of the cultivated fields in the United States. Inasmuch as most of these fields must continue to grow clean-tilled crops, the need for better protection against washing is obvious and urgent.

What happens on any hillside is a measure of the degree of unbalance between eroding forces and resisting power in that particular locality. Rainfall intensity, duration, frequency and time of occurrence, coupled with the length and steepness of ground slopes, constitute the chief eroding forces, while resisting power is determined largely by the infiltration and absorptive capacity of the soil and its inherent resistance to dislodgment when unprotected by any kind of vegetation such as during periods of seedbed preparation.

357. Diagrammatic Representation.—A diagrammatic representation of soil erosion and its effects, as conceived by L. D. Baver, is shown in Fig. 156. This chart might be considered a thumbnail summary of the foregoing discussion.

358. Kinds of Soil Washing.—Water erosion is generally considered to manifest itself in two forms: (1) sheet washing and (2) gullying. Usually these two forms represent different stages in the same process; and gullies, as a rule, do not appear until sheet erosion has been under way for a considerable time. Gullies, however, sometimes occur without being preceded by sheet erosion; and, conversely, sheet erosion has been known to continue indefinitely without the formation of gullies.

Sheet erosion is a rather uniform skimming off of the cream of the topsoil with every hard rain. The process is insidious because it may or may not leave any visible trace of damage and may continue for years under the eyes of an owner who does not realize his loss and cannot understand why the productivity of his land is rapidly decreasing.

Gully erosion.—Once water begins flowing in definite channels or gullies the eroding power of a given volume on a given slope is greatly increased, in accordance with certain well-known laws of hydraulics. On fields where erosion has been allowed to remain unchecked long enough for this to happen, not only are losses accelerated but the expense and difficulty of reclamation and control are greatly increased.

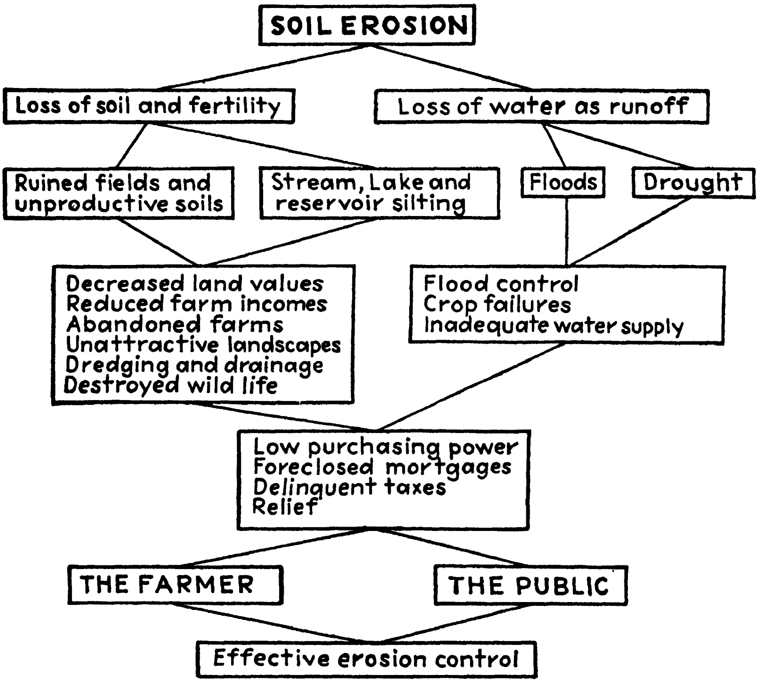

FIG. 156.—Chart showing how soil erosion affects the general public as well as the farmer. (*From Missouri Agr. Exp. Sta. Bull.* 349.)

There are two general types of gullying. Ditch erosion is where the head and sides of the gully are usually sloping and erosion occurs at the head, sides and bottom of the gully in varying degrees by the action of water, freezing and thawing. Waterfall erosion is caused by water falling over the edge of a gully or ditch bank and is often responsible for many of the deepest gullies. The falling water undermines the edge of the bank, which caves in, and the waterfall moves upstream. The undermining action of the waterfall goes on rapidly if the subsoil is an easily eroded type. Gullies formed by waterfall erosion may extend back through almost level land, as their growth usually depends on the fall, type of soil and size of drainage area furnishing water, rather than upon the slope of the land. Both types of gully erosion are often found in the same gully. Lateral gullies tend to form from the main gullies, and ultimately a network of gullies develops.

Wind Erosion.—Wind is directly responsible for sand and dust storms and is indirectly responsible for wave erosion along the shore lines of oceans and lakes.

Although wind action in the remote past is responsible for the formation of large areas of present-day farm land, it might seem that modern climatic conditions are not such as to permit wind erosion to attain major significance. Nevertheless, the dust storms attendant upon the drought of 1933–1934 reached terrific proportions and are likely to be repeated often as long as the conditions largely responsible for their cause remain uncorrected. Regardless of rainfall, it is becoming a matter of common experience for a zone of transition from humid to arid regions, extending westward from and including parts of Oklahoma, Missouri, Iowa, and Minnesota, to suffer dust storms of increasing frequency and severity.

A return to normal rainfall together with timber and shrub shelter belts, the planting of semiarid crops in alternating strips, the cessation of fall plowing in affected areas, and less intensive grazing all will help, but the problem can be solved completely only by modifying agricultural practices materially in semiarid regions, *i.e.*, reducing the proportion of total land area in annual cultivation and careful maintenance of adequate herbaceous cover on the rougher grazing lands.

359. Methods of Controlling Soil Washing.—Remembering that erosion cannot be prevented in an absolute sense and that the normal rates of run-off and erosion are those resulting from natural conditions of cover, the problem of control is largely a determination of where and how natural protection can be destroyed by tillage without inviting disastrous losses.

The first step in any rational solution is to restrict open cultivated land to slopes and conditions where erosion can be held within predetermined limits. This means that there will be certain slopes best suited for cultivated crops, steeper slopes best suited for permanent pastures, and still steeper slopes best suited for forests. The division between these three uses will not be a thin line but a border zone of considerable width and flexibility to allow for local variations.

This chapter will be concerned principally with ways and means of keeping erosion under control on slopes suited for cultivated crops. The difficulty of control is one factor that fixes the upper slope limit for crop land. Since soils vary in erodibility and since plants differ in holding power, it is evident that the maximum slope for a rate of loss considered tolerable will vary with the soil type and crop.

A control measure may roughly be evaluated and judged by asking the following questions:

How much is absorption increased and percentage of run-off reduced?

How much protection is afforded against damage by the residual run-off?

How much does it cost and how much is added to the inconvenience of tillage and annual cost of production?

How will the measure affect the cash income from the land?

How thoroughly has it been tested both experimentally and in actual practice?

The final practical answer to these questions pertaining to a particular farm will come as a result of field experience on that farm over a term of years. In most cases a combination of all recognized control methods will be needed for adequate protection.

All control measures now in common use seek to accomplish the results indicated in the first two questions. Absorption may be increased by improving the infiltration rate of the soil and by impounding the water where it falls, thus increasing the time of contact or the absorption opportunity. Under exceptionally favorable circumstances it may be possible to induce absorption of the entire rainfall, in which case there will be no run-off and no need to consider the second question.

Cropping System	Average Number of Days per Year Soil Is Uncovered
Continuous corn	207
Continuous wheat	91
Corn, soybeans, oats, cowpeas	259
Corn, oats, wheat, clover	95
Corn, wheat, clover	73
Corn, oats, clover	73
Corn, wheat, clover, timothy	18
Continuous bluegrass	0

All plants, including those grown as cultivated crops, have some anti-erosion value, but in varying degree, and, inevitably, tillage operations will cause bare soil to be exposed during times when erosive forces are usually most severe. The tabulation at the bottom of page 286 indicates the average number of days each year that soil is left uncovered under various cropping plans.

Similar data for cotton or tobacco, with their supporting rotational crops, would show substantially the same extent of exposure. These figures should not be interpreted to mean that erosion loss is necessarily in direct proportion to days of exposure, but they do mean that with any cultivated crop and any rotation scheme there is more or less opportunity for excessive erosion to occur. It is interesting to note that a 4-year rotation of corn, soybeans, oats, and cowpeas exposes bare soil 52 days longer than does continuous corn.

A very good measure of the effect of crops and cultivation is afforded by the data in Table 25, which gives the results of 14 years' plot measurements and observations at Columbia, Mo.

TABLE 25.—GENERAL SUMMARY OF RUN-OFF AND OF SOIL ERODED PER ACRE DURING FOURTEEN YEARS AT COLUMBIA, MO.[1]

	Cultural and cropping systems					
	Plowed 4 in. fallowed	Plowed 8 in. fallowed	Continuous bluegrass	Continuous wheat	Rotation—corn, wheat, and clover	Continuous corn
Average no. tons soil eroded per acre annually.	41.64	41.08	.34	10.10	2.78	19.72
Surface inches of soil eroded annually.	.291	.287	.0023	.070	.019	.138
Average no. cu. ft. run-off per acre annually.	46,132	45,836	18,379	35,209	21,129	44,524
Average per cent run-off annually.	30.7	30.3	12.0	23.3	13.8	29.4
Pounds run-off required to erode 1 lb. soil.	34.4	34.8	1,666.9	109.1	236.5	70.3
No. years to erode 7 in. of soil.	24	24	3,043	100	368	50

[1] *Mo. Agr. Exp. Sta. Research Bull.* 177.

The plots extended up and down a slope of 3.68 per cent, and each was 1/80 acre in size, being 6 feet wide and 90.75 feet long. The soil was a Shelby loam of "rather poor quality." Since the figures shown are averages over a considerable time period, they have quantitative value as representing the relative effect of fallow ground, bluegrass pasture, wheat, corn, and a 3-year rotation of corn, wheat, and clover on soil and water losses for the particular soil type and slope stated.

TABLE 26.—COMPARISON OF SOIL AND WATER LOSSES UNDER CROP ROTATIONS ON EIGHT IMPORTANT SOILS[1]

Location	Soil	Slope, per cent	Rotation	Mean precipitation, inches	Soil loss, tons per acre	Water loss, per cent of precipitation (run-off)
Bethany, Mo.	Shelby silt loam	8	Corn, wheat, clover	34	10	11
Columbia, Mo.	Shelby loam	3.7	Corn, wheat, clover	40	10	24
Hays, Kan.	Colby silt clay loam	5	Wheat, kafir, fallow	22	10	16
Guthrie, Okla.	Vernon fine sandy loam	7.7	Wheat, sweet clover, cotton	33	6	12
Temple, Tex.	Houston black clay	4	Cotton, corn, oats	27	6	5
Tyler, Tex.	Kirvin fine sandy loam	8.75	Cotton, corn, lespedeza	42	16	18
LaCrosse, Wis.	Clinton silt clay loam	16	Barley, corn, clover	29	21	13
Statesville, N. C.	Cecil sandy clay loam	10	Corn, wheat, lespedeza, cotton	43	7	10

[1] BENNETT, H. H., *Trans. Am. Geophys. Un.*, 1934.

Losses from experiments on a series of four plots on Cecil fine sandy loam in North Carolina have been measured over a period of 3 years by F. O. Bartel. The plots were 75 feet long on a slope of 9 per cent and were cropped, respectively, to grass sod, cotton annually, corn annually, and bare (hoed just enough to keep down weeds). The annual loss of soil per acre from the bare plot was 21 tons, from the cotton plot 20 tons, from the corn plot 13.5 tons, and from the sod plot 0.42 ton. Although the slope is much steeper than on the Missouri plots, the soil loss is less. The rainfall is a little more in North Carolina, 41 inches, while in Missouri it is 37 inches annually. This is further evidence of the great variation to be expected due to differences in erosive characteristics of soils.

The reduction in both soil losses and run-off brought about by various rotations on different soil types is apparent from a comparison of some of the data in Tables 26 and 27.

TABLE 27.—COMPARISON OF SOIL AND WATER LOSSES BY SURFACE RUN-OFF AT SEVERAL OF THE SOIL-EROSION EXPERIMENT STATIONS[1]

Area—soil type—inches rainfall	Plot treatment	Soil loss, tons per acre	Loss of rainfall (run-off), per cent
Upper Mississippi Valley, La-Crosse, Wis. Clinton silt loam. 16% slope. (1933 only) rain, 29.11.	Bare soil, uncultivated	51.5	15.9
	Continuous corn	59.9	19.2
	Continuous barley	12.0	17.8
	Continuous bluegrass	0.003	2.9
Mo.; Ia.; Bethany, Mo. Shelby silt loam. 8% slope. (Av. 3 yrs. 1931–1933.) Av. annual rain 33.53.	Bare	112.48	25.98
	Continuous corn	61.16	28.38
	Continuous bluegrass, timothy	0.36	7.72
	Continuous alfalfa	0.22	3.40
Red Plains; Guthrie, Okla. Vernon fine sandy loam. 7.7% slope. (Av. 4 yrs. 1930–1933.) Av. annual rain 32.92.	Bare	14.59	26.04
	Continuous cotton	28.05	14.18
	Bermuda grass	0.04	1.51
Tex.; Ark.; La. sandy lands region; Tyler, Tex. Kirvin fine sandy loam. 8.75% slope. (Av. 3 yrs. 1931–1933.) Av. annual rain 42.31.	Bare	12.20	18.20
	Continuous cotton	19.06	18.00
	Bermuda grass	0.20	1.50
Central Piedmont, Statesville, N. C. Cecil sandy clay loam. 10% slope. (Av. 3 yrs. 1931–1933.) Av. annual rain 42.9.	Bare	65.3	32.0
	Continuous cotton	14.0	9.7
	Continuous grass	0.8	5.2

NOTE.—All plots 72.6 feet long, 6 feet wide—1/100 acre.

[1] *U. S. Yearbook of Agr.*, 1935, p. 302.

360. Interpretation of Plot Data.—In arriving at correct conclusions from data obtained by plot measurements, certain definite limitations should be carefully considered:

With the exception of one plot at each federal station which was 145 feet, all the plots were less than 100 feet long.

All plots were only 6 feet wide, which precludes the possibility of lateral accumulation.

Losses are computed and reported on an acre basis, but were measured on plots 1/80 to 1/100 acre in size. In other words, the losses actually measured were multiplied in the tables on the assumption that unit losses in the plot would be the same as unit losses in a large field.

Some of the latest experiments on entire fields indicate that soil losses are approximately in the order of 1:7:15 for fields that are terraced, contour farmed, and farmed by ordinary prevailing methods. In other words, for each ton of soil lost from the terraced field there will be 7 tons from the contour-farmed field and 15 tons from the field farmed by ordinary methods, *i.e.*, with rows not on the contour.

361. Contour Farming.—When row crops are planted crosswise of a slope rather than running up and down, the rows act as miniature terraces and tend to hold rain water where it falls, thus increasing absorption and reducing run-off. If the rows are run up and down the slope, as is customary in many localities, each plow or cultivator furrow serves as a channel for rapid flow and results in inevitable gully cutting.

In a series of experiments at the Alabama Agricultural Experiment Station, Nichols found that a rain of 1 inch in 9 minutes (a rate of about 6 inches per hour) produced a very small soil loss on fields up to 10 per cent slope when the rows were across, but with rows paralleling the slope the loss approximated 1 ton per acre. On steeper slopes the rate of loss continued to increase rapidly and, on a slope of 20 per cent, amounted to 30 tons per acre from rows on the contour and 60 tons per acre from rows with the slope.

Table 28 gives a summary of other experimental data on the effect of various mechanical treatments on soil and water losses. The data should be considered as qualitative rather than quantitative, because of the short time measurements and other limitations. It is interesting to note, however, the apparent effectiveness of "hole-diggers," even on Shelby soil, and that there were no losses of either soil or water on Marshall silt loam in corn which was listed on contours. These experiments are also of interest as introducing plots of greater width and length than those heretofore used.

TABLE 28.—SOIL AND WATER LOSSES FROM FOUR IMPORTANT SOILS UNDERGOING DIFFERENT MECHANICAL TREATMENTS[1]

Treatment	Slope per cent	Rainfall, inches	Soil loss, tons per acre	Water loss, per cent of rainfall (run-off)
Spur, Tex.—Abilene clay loam				
Cotton, level terraces closed at ends	0.5	18.5	0.0	0.0
Cotton, contoured rows	0.5	18.5	.....	6.8
Cotton, rows down slope	0.5	18.5	.....	8.8
LaCrosse, Wis.—Clinton silt loam				
Corn, ordinary cultivator on contour	16	14	0.7	4.1
Corn, cultivated on contour with hole digger	16	14	0.09	0.02
Corn, rows sloped 5%, ordinary cultivator.	16	14	4.9	9.1
Corn, rows sloped 5%, cultivated with hole digger	16	14	0.4	2.5
Guthrie, Okla.—Vernon fine sandy loam				
Cotton, rows down slope	6.8	35	59.	13.7
Cotton, rows contoured	6.9	35	21.	11.3
Hays, Kan.—Colby silty clay loam				
Fallow, double-disc	4	14	2.8	10.8
Fallow, hole digger	4	14	0.6	3.9
Fallow, duckfoot down slope	4	14	3.4	13.9
Clarinda, Ia.—Marshall silt loam				
Corn, rows down slope (Plot 42′ × 530′)	8.4	26	34.5	9.4
Corn, rows down slope (Plot 42′ × 315′)	8·4	26	20.	9.5
Corn, rows down slope (Plot 42′ × 157.5′).	8.4	26	11.	11.5
Corn, rows on contour (Plot 42′ × 157.5′).	8.4	26	0.0	0.0

[1] BENNETT, H. H., *Trans. Am. Geophys. Un.*, 1934.

362. Strip Cropping.—By *strip cropping* is meant the practice of growing intertilled crops in alternating bands or strips with close-growing hay or small grain running crosswise of the slope and laid out to follow the contour of the land as nearly as possible. While not entirely new in some localities, practically no experimental data have yet been collected.

The practice is best suited to gently rolling land with uniform slopes but may occasionally be used on slopes quite steep. Usually strips of densely growing or fibrous-rooted crops, such as oats, wheat, barley, sorghums, alfalfa, clover, or grasses, are planted between strips of clean-tilled crops, such as corn, cotton, tobacco, soybeans, etc. The wider and closer together the strips of non-erosive crops are placed the more effective they are in checking erosion from the entire field, the object being, of course, to slow down the run-off velocity, filter out the soil, and increase absorption.

Tentative results in 1938 from a series of six plots 270 feet long by 90 feet wide using a rotation of corn, oats, and clover in 90- by 90-foot strips indicate that the combined losses from the three unstripped plots exceeds the combined losses from the three stripped plots in the ratio of 1.6:1.

Strip cropping may also be used as a prelude to terracing. When used in this manner the erosion-resisting crops are planted in bands 30 or more feet wide along the terrace lines which have been surveyed in the regular manner, usually with a grade. After the strips are harvested in the summer, the terraces can be built immediately, without damaging the principal crop in the field, while the summer work is slack and soil and weather conditions are favorable for terracing. This practice can be rotated from field to field until the farm is completely terraced.

Advantages of Strip Cropping.—Strip cropping costs but little and can be put into immediate practice. As a matter of fact it usually costs no more than does the inauguration of a regular good rotation. No surveying is necessary, though it may be advisable. If the lines are surveyed, this may be done by anyone who understands the use of an ordinary farm level. There is no labor necessary other than that required for the production of the crops being grown. There are no obstructions to interfere with the use of any type of farm machinery. There is no appreciable upkeep required. The length of rows may actually be increased in many cases, and since these rows run more or less on the level the draft in pulling farm tools will be greatly reduced. This point was nearly always stressed by farmers near LaCrosse, Wis., where strip cropping is a common practice. Strip cropping does not materially interfere with any cropping system determined as best for a farm. It may be used with or without terraces and is a valuable supplement to terracing on fields of 8 per cent slope or greater.

Disadvantages of Strip Cropping.—Strip cropping is difficult to lay out on very irregular or badly cut up fields. It is not likely to prove satisfactory where at least a good portion of the strips cannot be made nearly uniform in width throughout their length. A considerable amount of irregularity, however, can be taken care of by seeding permanently to grass, alfalfa, etc., the odd-shaped correction areas, or by increasing the width of the small grain or sod strips so as to include these irregular portions as indicated below.

In strip cropping, as in all contour farming, it is not possible to have straight rows or checked crops. These objections are generally more imaginary than real, however, on fields that are really suitable for stripping. It is usually not so necessary to check crops where rotations are practiced, as weeds are not likely to be serious, and a better control of weeds is about the only valid reason for checking.

Some pasturing of meadow aftermath may be lost if strips cannot be fenced, and such fencing is usually not practicable. Even this objection can be largely overcome, however, where it is possible to strip-crop two fields of similar size. In this case corn or cotton and first-year meadow might be grown in alternate strips in one field and in the other field small grain and second-year meadow might be similarly arranged. The latter field should be pastured as soon as the grain and hay crops are removed, while, in the former, pasturing of the aftermath would be delayed until after the principal crop had been harvested.

363. Contour Ridging.—A practice known as *contour ridging* has recently come into favor in the development of permanent pastures on steep slopes to be retired as submarginal land and in the improvement of old pastures that have been damaged by drouth and overgrazing.

Development of pastures on such areas frequently entails removal of brush, weeds, sprouts, and other scattering growth of grass and affords very little protection to the soil during heavy rains.

In preparing a pasture for contour ridging the following sequence of steps should be observed:

Remove stumps, and deaden and remove undesirable trees.
Rid pastures of weeds by mowing, pulling, or hoeing.
Level old beds or terraces.
Plow in gullies.

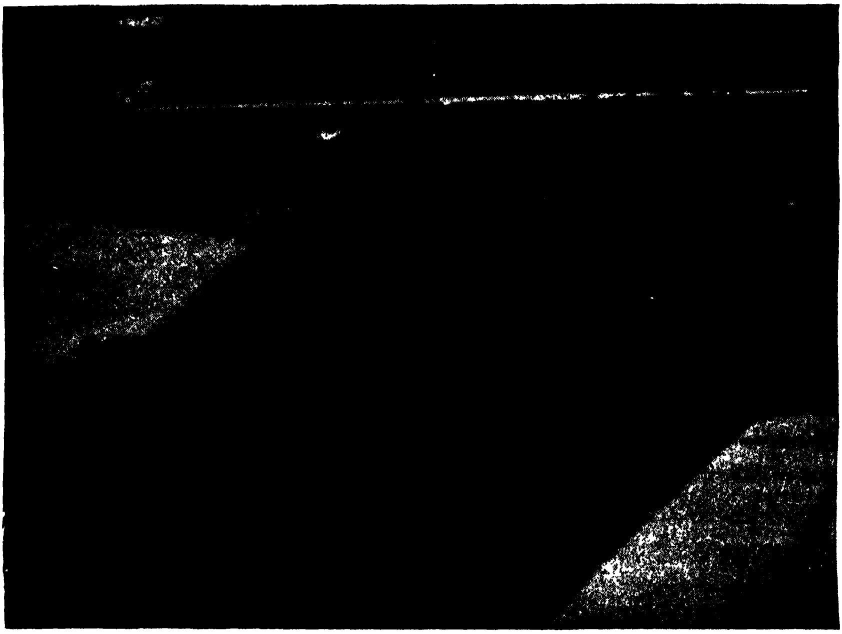

FIG. 157.—Air view of pasture contour ridges made with long-winged terrace plow at College Station, Tex. (*Courtesy of G. A. Kelly Plow Company.*)

If contour ridges are to be built on land being retired from cultivation, the sowing of oats or other small grain in advance of the construction of the ridges is recommended.

When laying out and constructing the ridges, the work should be done in the following order:

Check level and be sure it is in adjustment.

Set up level and run first contour line near top of slope. (Set stakes at 25-foot intervals.)

Step 12 feet downhill at the point of the steepest slope and run second line on level. Continue until all lines are run.

Walk out each contour line and mark the lines with a plow. A shovel plow is best suited for this purpose.

Plow one round with a 12-inch turning plow beginning 6 to 8 feet below contour line and throwing the soil downhill first.

Turn furrows up at each end, and *do not* cross depressions or gullies. Turn furrows uphill, and stop at the point where the land begins sloping off into a depression or gully.

Complete ridge by making one or more rounds with a long-winged terracing plow, beginning on the downhill side and throwing the soil uphill first. In completing the round on the uphill side start the terracing plow on true contour line, which was marked off with a plow as stakes are removed. (If a long-winged terracing plow is not available, one may be made by wiring a 1- by 6-inch board 30 inches long to the plow wing.)

In order to prevent water from concentrating in possible low places in contour ridging and causing breaks, each contour ridge should be blocked off every 25 feet on each side of any depression, by making a small dam across the channel with a few shovels of earth.

364. Use of Terraces.—The control of erosion by terracing is primarily a problem of surface drainage somewhat analogous in principle to the removal of storm water from city streets by curbs, gutters, catch basins, and sewers. As shown by Fig. 158, modern terraces are nothing more than a series of broad flat undulations thrown up at intervals across a hillside and usually built with a slight longitudinal grade to carry the excess water off the field at low velocity. In effect each terrace acts as a shallow diversion ditch that intercepts the run-off from its individual catchment area and leads it away slowly before the water has a chance to attain harmful velocity or volume.

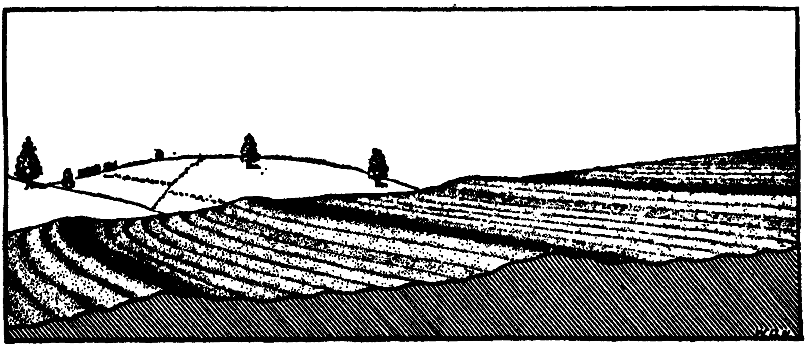

FIG. 158.—Diagram illustrating the use of modern terraces as commonly constructed on cultivated hillsides.

Inasmuch as terraces must be carefully planned and constructed according to definite standards, the discussion in this chapter will be limited to general phases, leaving the details for later treatment.

On cultivated lands subject to erosion, terracing is one of the very few control measures of widespread adaptation that has been thoroughly tested and found acceptable under actual farm conditions. This is not to be wondered at in view of the fact that growing cultivated crops on sloping hillsides exposes bare soil to the elements and is essentially an unnatural or artificial practice that would logically require some form of unnatural or artificial control as a counteragent.

Looked at from this point of view, terracing is regarded as a desirable concomitant of contour farming and the use of such soil-building and soil-holding crops as can be grown most satisfactorily in a rotation. As developed to suit modern field culti-

TABLE 29.—ANNUAL RUN-OFF AND SOIL LOSSES FROM TERRACED AND UNTERRACED LAND[1]

Station and year	2 Rainfall	3 Treatment	4 Slope	5 Soil loss	6 Per cent	7 Run-off	8 Crops
Guthrie, 1931...	27.3	Terraced	5.5	1.25	2.8	10.7	Young oats, mature[a] cowpeas, fallow
		Unterraced	5.1	43.90		22.7	
Guthrie, 1932...	36.2	Terraced	5.5	4.06	4.6	23.3	Fallow, cotton, winter wheat
		Unterraced	5.1	88.06		30.8	
Guthrie, 1933...	30.4	Terraced	4.6	1.33	2.2	21.9	Winter wheat, cotton, later grass in cotton
		Unterraced	5.1	60.39		14.1	
Average...... Guthrie.......	31.3	Terraced		2.21	3.4	18.6	
		Unterraced		64.12		22.5	
Tyler, 1933.....	45.7	Terraced	5.8	4.55	11.1	14.0	Cotton followed by fall oats
		Unterraced	7.5	41.03[b]		16.5	
LaCrosse, 1933..	26.8	Terraced	12.7	2.23	7.0	4.9	Barley followed by clover
		Unterraced	13.1	31.70		8.9	
Bethany, 1933..	31.7	Terraced	8.3	3.19	11.8	18.7	Corn followed by sweet clover; winter wheat following peas
		Unterraced	6.7	27.09		19.2	
Pullman, 1932..	24.4	Terraced	20[c]	2.85	12.6	10.0	Winter wheat
		Unterraced	20[c]	22.53		24.8	Winter wheat stubble
Pullman, 1933..	28.8	Terraced	20[c]	3.53	31.3	12.4	Winter wheat stubble, fallow
		Unterraced	20[c]	11.26		37.3	
Average...... Pullman......	26.6	Terraced		3.19	22.0	11.2	
		Unterraced		16.90		31.0	

[1] RAMSER, C. E., *Bureau of Agr. Eng., U. S. Dept. Agr. Soil Erosion Exp. Sta.*

[a] Crops for terraced area. Unterraced area winter rye, mature cowpeas and winter wheat. For others years and all other stations the terraced and unterraced areas were similarly cropped as shown.

[b] Gullies and watercourse protected by brush dams.

[c] Approximate.

Col. 2. Annual rainfall in inches.
Col. 4. Slope in feet per 100 feet.
Col. 5. Soil losses in tons per acre.
Col. 6. Terraced loss in per cent of unterraced.
Col. 7. Runoff in per cent of rainfall.

vation practices, terraces can and do save rich topsoil in the magnitude order of 30 to 40 tons per acre per year when fields are in clean-tilled row crops and half as much when in small grain.

The exact figures for both soil and water savings so far as available for five of the federal erosion experiment stations are given in Table 29. While these data are not conclusive as to the causes of variations between the stations and as to run-off eccentricities, they are remarkably consistent in showing large savings of soil due entirely to the terraces. Attention is invited particularly to the 1932 figures for the Red Plains Station near Guthrie, Okla., where a saving of 84 tons per acre was recorded for the terraced field over that for the unterraced on a moderate slope of 5 feet per hundred. Both fields were fallow until May 15; in cotton from May 15 to October 15; and in winter wheat for the rest of the year.

In the 1934 *Yearbook of the U. S. Department of Agriculture* there is reported a loss of 150 pounds per acre from terraced land in barley at LaCrosse, Wis., whereas an unterraced field, similarly cropped, lost 7,120 pounds per acre. Both losses were occasioned by two rains totaling 3.5 inches.

At Bethany, Mo., a single rain of 1.17 inches on a field of wheat produced a loss of 2,100 pounds per acre from the unterraced portion and only 60 pounds from the terraced part. According to C. E. Ramser, until recently in charge of the engineering investigations at all the federal stations, the two portions of this field are comparable in every practicable way, including the total number of years that each has been in cultivation.

All losses of soil and water from both the terraced and unterraced fields at all the stations were carefully and accurately measured in silt boxes and flumes equipped with automatic recording instruments. In the case of unterraced fields, large boxes were placed at the lower side in such a position that all water and soil leaving the field were forced to enter and be measured. On terraced fields the flumes and silt boxes were placed at the outlet of each terrace.

Since the distance between terraces is about the same as the length of the experimental plots previously discussed, it might seem that there would be some relation between the unit losses measured at the terrace outlet and the plot measurement for similar soil, slope, and crop. Undoubtedly there is, but it is complex owing to similitude effect between narrow plot and wide field and to a multitude of minor dissimilarities. Certainly, if the soil passing the terrace outlet is less in amount than that measured from a comparable plot, there would seem to be little basis for assuming that the difference eventually escapes from the field without being measured. Elevations taken every foot along profile lines at right angles to the terraces at least once a year do not show progressive soil movement down the slope, or at least it is so slight as to be negligible. While not conclusive, results so far show little difference between terraced and unterraced land in this respect. Even if the channel did silt half full, proper plowing with a dead furrow in the channel would leave only part of the silt to be thrown on the bank where, being exposed only to rain that falls directly upon it, it is in a much less vulnerable position than it would be if similarly located on unterraced ground. Furthermore, since the clean-out soil is seldom if ever lifted clear over the crest of the bank, such washing as does occur will be back into the channel.

The disadvantages of terraces are, of course, that they are somewhat costly to build and troublesome to maintain; they may require abrupt changes in traditional farming practice; damage may be caused by diversion and concentration of water at unnatural exits; on thin land subsoil may be exposed in the terrace channels; and, finally, unless they match the ground perfectly and are inspected and repaired if necessary after each rain for the first year or two, they may do more harm than good. Terraces emphatically are not a cure-all and are dependent upon the mutual support of good farming and cropping practices to produce best results.

On the other hand, none of these disadvantages are especially difficult to overcome if one is really conservation minded, and the alternative in most cases is complete exhaustion and abandonment of the land after a few years of exploitation. The advantages of soil insurance; moisture conservation (in regions of low rainfall and open soils, terraces are built level with closed ends); consolidation of gains from lime and fertilizer applications; increased crop yields; and higher land values, exceeding by several times the normal terracing cost, are very generally considered to outweigh any disadvantages involved by a good margin. The best proof of this is the widespread use of terraces over a long period of years and their universal popularity with practically all progressive farmers who have granted them a fair trial. Today (1939), upward of 20,000,000 acres of cultivated land are "terrace farmed" in the United States, and the practice is growing by leaps and bounds into areas not heretofore considered vulnerable to erosion. Terraces are least costly and most efficient when used as conservators of virgin soil when first it is put under the plow and are at their worst when used in an attempt to restore to cultivation lands already stripped of topsoil and disfigured with gullies.

CHAPTER XXII

TERRACING

Terracing as an art is as old as agriculture itself. As a science it dates from 1886, when P. H. Mangum, a farmer of Wake Forest, N. C., began to experiment with a "modified terrace" which would permit crossing with farm implements and allow the entire hillside to be cultivated. The following quotation from *The Progressive Farmer* of March, 1888, is of interest.

> Mr. Mangum had perhaps the best system of hillside ditches in Wake County a few years since (1886) when he read of the level terrace system practiced to some extent in Georgia. He tried this system fairly on 25 acres and found that it would not do for his farm, which is a good representative tract of middle and Piedmont, North Carolina land. Finally Mr. Mangum worked out the scheme of the "modified terrace" which we saw and which I will briefly describe: He utilized his hillside ditches, plowing down the upper bank several times using hoes where necessary, allowing the lower embankment of the ditch to remain. In front of the embankment, where the ditch was, is a space of 10 feet on a dead level (crosswise) and about 12 inches below the embankment.

365. Terrace Types.—The terrace built by Mangum in 1886 is the progenitor of the modern broad-base ridge-type terrace that is in practically universal use today. The narrow-base ridge type failed to establish itself in popularity because of numerous breaks in the bank and because it could not be cultivated or crossed. Also the narrow deep channel, above the ridge, is poorly proportioned hydraulically to carry maximum discharge at minimum velocity.

In continental United States, terraces of the bench type are of little more than academic interest, owing to the large amount of earth moving involved and to the fact that they seriously impede if not prohibit the use of cultivating machinery. Bench terraces are also objectionable because of the large amount of subsoil exposed on the ground surface, even where the terraces have been allowed to develop over a period of years by allowing the soil to move down the slope. Nevertheless, if cultivated crops are to be grown in mountainous regions, bench terraces or their counterpart are essential. This is attested to in many parts of the world today, notably in China and Japan, in the vineyards of Europe, and in the rice fields of the Philippine Islands. Figure 159 illustrates a view of what is described as the world's most extensive terraced rice fields, located in the Philippine Islands. These terraces are the result of long centuries of toil by native tribes.

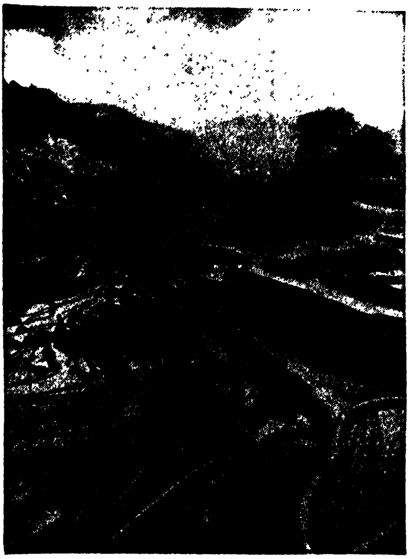

FIG. 159.—Bench terraces in the Philippine Islands. World's most extensive terraced rice fields. (*Courtesy of U. S. Bureau of Agricultural Engineering.*)

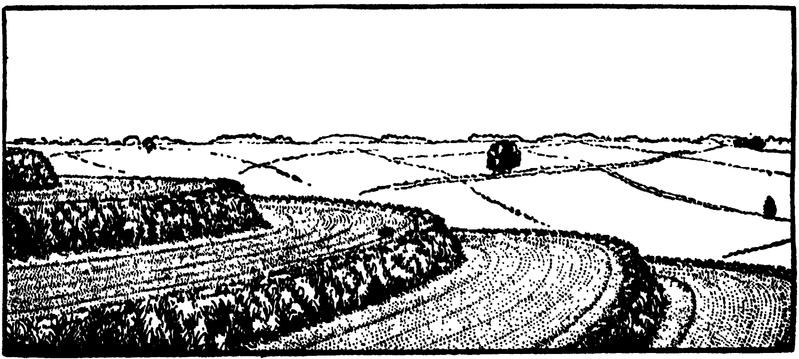

FIG. 160.—Bench terrace. (*U. S. D. A. Farmers' Bull.* 1386.)

Typical bench terraces, as they exist in the United States, are illustrated in Fig. 160.

Although bench terraces typify the true meaning of the word "terrace" more nearly than any other type, they are not practicable on the cultivated lands of continental United States on any extensive scale; and, since narrow-base ridge terraces are practically obsolete, whenever the word "terrace" is used hereafter it will refer to the broad-base, shallow-channel type.

Some authorities advocate a further refinement by dividing broad-base terraces into (1) the drainage or channel type and (2) the absorption or ridge type. Typical cross-sections of these two types are shown in Fig. 161.

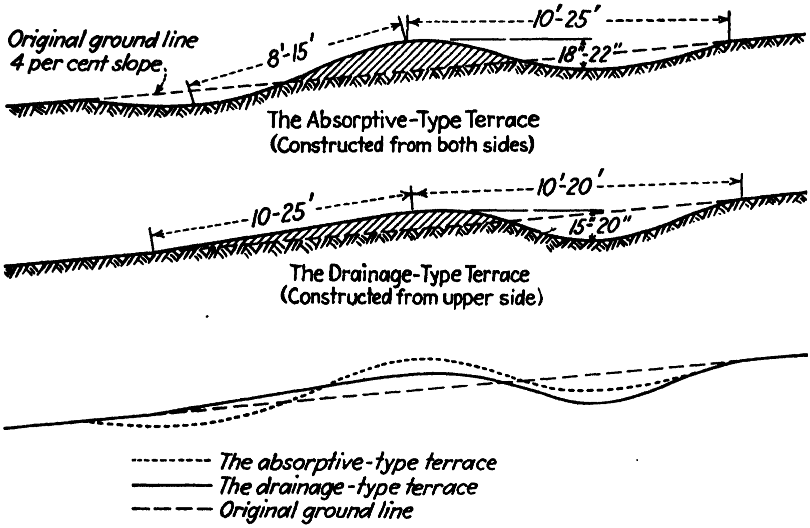
Original ground line
4 per cent slope
8'-15'
10'-25'
18"-22"
The Absorptive-Type Terrace
(Constructed from both sides)
10-25'
10'-20'
15"-20"
The Drainage-Type Terrace
(Constructed from upper side)
The absorptive-type terrace
The drainage-type terrace
Original ground line

FIG. 161.—Typical terrace cross-sections after settlement and cultivation.

366. Design Principles.—In principle, terracing is essentially a process of constructing a series of drainage channels across the slope of hillsides, whose function is to collect the run-off water before it attains harmful velocity and to conduct it slowly to an erosion-proof outlet. The drainage channels, which intercept the run-off and prevent its rapid flow down the slope, are formed by throwing up low, broad embankments called *terraces*. The first terrace is located near enough to the crest of the slope to prevent the start of appreciable erosion, and the others are so spaced down the hillside as to serve the same purpose. Ordinarily the embankment is not constructed precisely on the contour but is given a slight fall longitudinally, so that the water that collects in the channel next to the embankment is conducted along the terrace to a suitable outlet, usually located at a boundary of the field. Very often the outlet is a ditch on a steep grade that must itself be protected against wash.

The size and fall of the terrace channel must be adjusted to carry the maximum run-off without danger of appreciable scour or overtopping. Maximum or critical run-off is fixed by the formula $Q = CIA$, as has been pointed out in a previous chapter. The A in the formula is a function of the length of the terrace and the spacing between it and the adjacent terrace above—or to the top of the hillside.

C, being a coefficient of imperviousness, is essentially a measure of the percentage of rainfall running off during and after any given storm. Probable values of C for different types of bare soil, under the conditions described, are given in Table 30. These figures are useful for determining the storage capacity required above absorptive type terraces and storage dams.

TABLE 30.—PROBABLE PERCENTAGES OF RAINFALL RUNNING OFF, FOR THE DIFFERENT TYPES OF SOIL, AND FOR A RAINFALL OF 8 INCHES IN 48 HOURS

Kind of soil	Approximate percentage of silt and clay in the soil	Run-off, percentage rainfall							
		Open, pervious subsoil. Slope of land, feet per hundred				Impervious subsoil.[1] Slope of land, feet per hundred			
		5	10	15	20	5	10	15	20
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Sandy	20	40	45	50	55	45	50	55	60
Sandy loam	40	50	55	60	65	55	60	65	70
Clay loam	60	65	70	75	80	70	75	80	85
Clay	80	80	85	90	95	85	90	95	100

[1] The word *impervious* should be construed to mean that the subsoil admits water but much more slowly than an open, pervious subsoil.

NOTE.—If soil is deeply plowed and contains much humus, deduct 10 from the above values.

To prevent overtopping in a drainage-type terrace or diversion ditch the carrying capacity must equal or exceed the maximum *rate* of run-off likely to occur under the most unfavorable conditions, *i.e.*, when the soil is saturated or partly frozen. It is believed that the values of C heretofore given (see Table 19), together with a rainfall intensity rate of 6 inches per hour, will yield satisfactory practical results.

On this basis, for example, the required capacity at the lower end of a 1,500-foot terrace, 60 feet below the next terrace above, on a land slope of 10 per cent with clay loam soil, open subsoil, would be computed as follows:

Q = required capacity in cubic feet per second.
$C = 0.72$ (per cent of rainfall).
$I = 6.0$ inches per hour.
$A = 1{,}500 \times 60/43{,}560 = 2.07$ acres.
Therefore

$$\begin{aligned} Q &= CIA \\ &= 0.72 \times 6.0 \times 2.07 \\ &= 8.94 \text{ cubic feet per second} \end{aligned}$$

367. Terrace Spacing.—Since the allowable spacing is governed mainly by the need for preventing appreciable erosion between the terraces, it will vary with the land slope for given soil and cultural conditions. For the sake of economy in construction and minimum interference with cultivation, it is desirable to space the terraces as widely as the soil and slope will permit without requiring too much maintenance at a time when the land is in the least resistant crop. Wide spacing calls for more capacity in the terrace channel to serve the larger watershed. Good cultural practices permit maximum spacing and, by increasing the time of concentration, reduce to a minimum the critical rate of rainfall and the run-off coefficient.

Trial spacings are usually expressed in feet of vertical drop from one terrace to the next as a function of the land slope. For instance, the vertical interval (or drop) in feet for Southern states may roughly be expressed as 2, plus the land slope in per cent divided by 4, and for Northern states 2, plus the land slope in per cent divided by 3. Thus, if the terrace system is located in Mississippi on a slope of 8 per cent the vertical interval would be 4 feet.

Table 31 represents what is generally considered to be good average practice and includes permissible variation of 15 per cent above and below the mean to allow for changeable conditions as to soil characteristics, tillage, cropping practices, and the other factors previously discussed.

TABLE 31.—RECOMMENDED TERRACE SPACINGS[1] AND RELATED DATA FOR DRAINAGE-TYPE TERRACES[4]

Southern States—$VI = 2 + \frac{S}{4}$

Per cent Slope (S),	Vertical interval (VI), feet			Horizontal distance, feet			Acres per mile of terrace[2]			Acres per 100 feet of terrace[2]			Feet of terrace per acre[2]		
	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3]	Mean	Maximum[3]	Minimum[3] spacing	Mean spacing	Maximum[3] spacing
1	1.70	2.00	2.30	170.00	200.00	230.00	20.60	24.24	27.88	0.390	0.459	0.528	256.23	217.80	189.39
2	2.12	2.50	2.87	106.25	125.00	143.75	12.88	15.15	17.42	0.244	0.287	0.330	409.98	348.48	303.03
3	2.34	2.75	3.16	77.92	91.67	105.42	9.44	11.11	12.78	0.179	0.210	0.242	559.03	475.18	417.16
4	2.55	3.00	3.45	63.75	75.00	86.25	7.73	9.09	10.45	0.169	0.172	0.198	683.29	580.80	505.00
5	2.76	3.25	3.74	55.25	65.00	74.75	6.70	7.88	9.06	0.127	0.149	0.172	788.42	670.15	582.74
6	2.97	3.50	4.02	49.58	58.33	67.08	6.01	7.07	8.13	0.114	0.134	0.154	878.58	746.79	649.37
7	3.19	3.75	4.31	45.53	53.57	61.61	5.52	6.49	7.47	0.105	0.123	0.141	956.73	813.14	707.03
8	3.40	4.00	4.60	42.50	50.00	57.50	5.15	6.06	6.97	0.098	0.115	0.132	1,024.94	871.20	757.56
9	3.61	4.25	4.89	40.14	47.22	54.31	4.86	5.72	6.58	0.092	0.108	0.125	1,085.20	922.49	802.06
10	3.82	4.50	5.17	38.25	45.00	51.75	4.64	5.45	6.27	0.088	0.103	0.119	1,138.82	968.00	841.74
11	4.04	4.75	5.46	36.70	43.18	49.66	4.45	5.23	6.02	0.084	0.099	0.114	1,186.92	1,008.80	877.16
12	4.25	5.00	5.75	35.42	41.67	47.92	4.29	5.05	5.81	0.081	0.096	0.110	1,229.81	1,045.36	909.01
Northern States—$VI = 2 + \frac{S}{3}$															
1	1.70	2.00	2.30	170.00	200.00	230.00	20.60	24.24	27.87	0.390	0.459	0.528	256.23	217.80	189.39
2	2.27	2.67	3.07	113.47	133.50	153.52	13.75	16.18	18.61	0.260	0.306	0.352	383.89	326.29	283.74
3	2.55	3.00	3.45	85.00	100.00	115.00	10.30	12.12	13.94	0.195	0.230	0.264	512.47	435.60	378.78
4	2.83	3.33	3.83	70.76	83.25	95.74	8.58	10.09	11.60	0.162	0.191	0.220	615.60	523.24	454.98
5	3.12	3.67	4.22	62.39	73.40	84.41	7.56	8.90	10.23	0.143	0.168	0.194	698.19	593.46	516.05
6	3.40	4.00	4.60	56.67	66.67	76.67	6.87	8.08	9.29	0.130	0.153	0.176	768.66	653.37	568.15
7	3.68	4.33	4.98	52.58	61.86	71.14	6.37	7.50	8.62	0.121	0.142	0.163	828.45	704.17	612.31
8	3.97	4.67	5.37	49.62	58.38	67.13	6.01	7.08	8.14	0.114	0.134	0.154	877.87	746.15	648.89
9	4.25	5.00	5.75	47.22	55.56	63.89	5.72	6.73	7.74	0.108	0.128	0.147	922.49	784.02	681.80
10	4.53	5.33	6.13	45.30	53.30	61.29	5.49	6.46	7.43	0.104	0.122	0.141	961.59	817.26	710.72
11	4.82	5.67	6.52	43.81	51.55	59.28	5.31	6.25	7.18	0.101	0.118	0.136	994.29	845.00	734.82
12	5.10	6.00	6.90	42.50	50.00	57.50	5.15	6.06	6.97	0.098	0.115	0.132	1,024.94	871.20	757.56

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[1] The spacings are based on recommendations of C. E. Ramser.

[2] Includes only the interval above each terrace.

[3] The minimum is 15 per cent below the mean, and the maximum 15 per cent above.

[4] *U. S. Dept. Agr. Farmers' Bull.* 1789.

The major criterion in all cases is prevailing land slope, and this itself is subject to considerable variation in any given field so that, regardless of the spacing scale adopted, it can seldom be applied to the ground with absolute precision. It is common practice to measure the slope above the mid-point of a terrace and allow that to govern the spacing between it and the one next above. Appreciable reduction in land slope may so increase its length in comparison with the one next above as to require the use of an intermediate spur terrace to avoid abnormally large spacing.

368. Terrace Grades.—Successful terraces have been built with a variety of gradients (fall along the terrace water channel) as follows: level end to end; graded uniformly from one end to the other or from a point near the middle toward each end; with a grade varying from a minimum in the upper portion to a maximum at the lower end.

It is desirable, within practical limitations, to keep terrace grades as slight as possible and still impart sufficient velocity to the water to prevent overtopping or ponding.

That it is important to use the smallest permissible gradient is clearly evident from Table 32, which shows run-off and soil losses for terraces with different grades at several of the federal stations. This table shows losses for a 6-inch grade at Bethany nearly five times as much as for terraces with a level grade and about three times as much as a 2-inch grade, with substantially similar results at Guthrie. Since the main object of terracing is to retain as much soil as possible on the field, especially the rich silt lodging in terrace channels, these experiments indicate that a grade of 4 inches or 0.33 foot per 100 feet is about the maximum that should be used. Certainly a gradient of 0.4 per cent should not be exceeded except in very special circumstances.

Level Terraces.—Level terraces are satisfactory where the soil is sufficiently open to allow a rate of infiltration approximately equal to the rate of run-off or in regions of sparse rainfall where every drop of water counts. In the latter case it is frequently feasible to close both ends and force all surface water to soak into the ground. When terraces are built level, extreme care is needed to prevent low places developing in the bank with consequent outpouring of water from both directions along the terrace. This would not be so likely to happen with a graded terrace.

TABLE 32.—RUN-OFF AND SOIL LOSSES FOR TERRACES WITH DIFFERENT GRADES AT SEVERAL OF THE SOIL EROSION STATIONS

Terrace number	Land slope, per cent	Vertical spacing, feet	Length, feet	Grade, inches per 100 ft.	Average annual			Crops
					Soil losses, tons per acre	Run-off, per cent of rainfall	Rainfall, inches	
Guthrie Station (Three-year Period)								
3-C	4.3	3.5	1500	6	7.79	20.2	....	1931—Oats
4-C	4.4	3.5	1500	4	4.29	20.6	31.3	1932—Cotton
5-C	4.7	3.4	1500	2	3.53	20.6	....	1933—Corn
6-C	5.5	3.3	1500	0	2.05	16.6		
Bethany Station (Two-year Period)								
5-C	12 (approx.)	5 (approx.)	1200	8	3.92	13.2		
6-C	12 (approx.)	5 (approx.)	1200	6	1.87	12.0	....	1932—Corn
7-C	12 (approx.)	5 (approx.)	1200	4	1.66	12.0	29.4	1933—Oats followed by clover and
8-C	12 (approx.)	5 (approx.)	1200	2	0.68	11.0		timothy
9-C	12 (approx.)	5 (approx.)	1200	0	0.42	6.8		
Tyler Station (Three-year Period)								
5-C	6.3	4	700	0 to 6	10.1	29.8	42.3	1931—Cotton 1932—Corn 1933—Cotton } followed by rye and oats cover crop
6-C	5.9	4	700	0 to 3	4.9	16.2	....	
LaCrosse Station (One Year)								
4-A	15 (approx.)	7	1400	0 to 6	7.1	....	....	1933—Barley followed by corn
5-A	15 (approx.)	7	1400	0 to 3	2.0	....	26.8	
6-A	15 (approx.)	7	1400	0	0.6			
Pullman Station (One Year)								
15	24.0	17.0	685	24	13.67	29.3		
16	26.7	13.5	780	18	11.40	23.2	....	Winter wheat stubble
17	23.5	14.2	780	12	9.05	13.6	28.8	1933—Fallow
18	18.4	14.0	780	6	3.65	11.6		Winter wheat
19	15.2	13.8	780	0	1.28	15.1		

The spacing recommended in *U. S. Department of Agriculture Bulletin* 1669 for level terraces on slopes of 10 per cent or less are:

Soil	Vertical Drop in Feet between Terraces
Sandy	4.5
Sandy loam	3.5
Clay loam	2.5
Clay	2.0

For steeper slopes these values may be increased ½ foot, and for terraces with open ends on permeable soils the same spacings as given in Table 31 will apply. Spacings 1 foot less than those given for the Southern states are appropriate for regions of light rainfall where crops normally suffer severely from drouth.

Graded Terraces.—The advantages of a terrace with uniform grade are (1) ease with which it can be staked out, (2) less maintenance in removing silt from channels, and (3) less likelihood of ponding due to operation of field machinery in the channel.

While uniformly graded terraces have their stanch advocates, these advantages are not generally deemed sufficient to outweigh the savings in both soil and water obtainable from the use of a variable grade and other advantages.

Again, the variable grade is more logical because the capacity increases with increased run-off, and this can be accomplished only by increasing the grade of terraces of constant cross-section. It is always desirable to hold back the water as much as possible without ponding or undue hazard to the embankment, and this is assured more nearly by a variable grade, provided of course that the work of surveying and construction is accurately done.

It is common practice to divide a variable-graded terrace into sections of 300 feet in length and increase the grade of each section progressively from the upper end toward the outlet approximately in accordance with the range of figures in Table 33. Where the length is not in excess of 300 feet a uniform grade of 0.15 to 0.30 per cent is satisfactory. Occasionally a very long terrace seems unavoidable, in which case the sections may be made about one-fifth of the total length with the maximum gradients for each section as shown in Table 33. The other and less desirable alternative is to build up the bank at the lower end high enough to carry the additional discharge. For unusually impervious and scour-resistant soils, grades up to 0.50 per cent

TABLE 33.—GRADIENTS FOR VARIABLE-GRADE TERRACES

Length of terrace, feet	Fall along terrace	
	Inches per 100 feet (minimum)	Feet per 100 feet (maximum)
0 to 300	Level	0.10
300 to 600	1	0.15
600 to 900	2	0.20
900 to 1200	3	0.30
1200 to 1500	4	0.40

may sometimes become necessary but should be used as sparingly as possible.

369. Length of Terraces.—Experiments at the federal erosion stations indicate that long terraces produce more soil loss but less run-off than short ones. The maximum length of terrace, however, for a run in one direction should probably not exceed 2,000 feet under any circumstances, and it is desirable to keep under 1,200 feet if at all possible. Very long terraces require either impermissible grades or abnormally large cross-sections or both to take care of the accumulated volume of water in their lower reaches. Large grades induce high velocities, which erode the channel; and large cross-sections mean high banks, which impede the use of field machinery.

On the other hand, short terraces are somewhat more troublesome and expensive to build, owing to the extra time consumed in turning at the ends.

Sometimes, as an extreme measure, it becomes necessary to use natural depressions in the middle of fields as outlet ditches in order to keep the terrace lengths within limits. This entails special precautions to prevent washing in the outlet ditch and, by dividing the field, introduces wasteland and added inconvenience in cultivation.

370. Terrace Cross-sections.—Theoretically it is possible to design terrace cross-sections on the same basis that open ditches are designed for irrigation and land drainage, by adjusting the width and depth to provide sufficient waterway area to accommodate the critical run-off. Critical run-off is computed by the method explained in Chap. XII and, when this is known, the terrace channel is made to equal or exceed it in carrying capacity, without resort to erosive velocities or to side slopes and bank heights that would cause undue interference with cultural practices.

371. Capacity Formula.—When the grade and dimensions of a channel are known, its carrying capacity may be computed from the formula

$$Q = a\frac{1.486}{n}R^{2/3}S^{1/2}$$

where Q = carrying capacity or discharge in cubic feet per second.

a = cross-sectional area of channel in square feet.

n = a coefficient whose value depends on the degree of roughness or irregularity in the channel.

$R = a/p$ = the "hydraulic radius," which is the quotient of the cross-sectional area divided by the "wetted perimeter," p, or length of the cross line of contact between the water and the channel sides and bottom.

S = grade or rate of fall *expressed in feet per foot.*

When it is considered that the two-thirds power of R is simply the cube root of R squared and that the one-half power is the square root of S, it is seen that the formula is not so complex as it may first appear and yet is quite flexible and accurate. This formula is a combination of Manning's velocity formula

$$V = \frac{1.486}{n}R^{2/3}S^{1/2}*$$

Where

V is the lineal velocity of flow in feet per second and

$$Q = aV$$

the discharge of a conduit of any shape being the product of the cross-sectional area times the lineal velocity.

For terrace channels that bear growing crops part of the time, a value of n = 0.04 is generally considered proper. At times when the growth is dense enough to greatly increase this value and cause overtopping, it is probable that little damage will be done. Values of n to fit a great variety of conditions have been

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* See Tables 46 and 47 in the Appendix giving two-thirds powers of R and square roots of S.

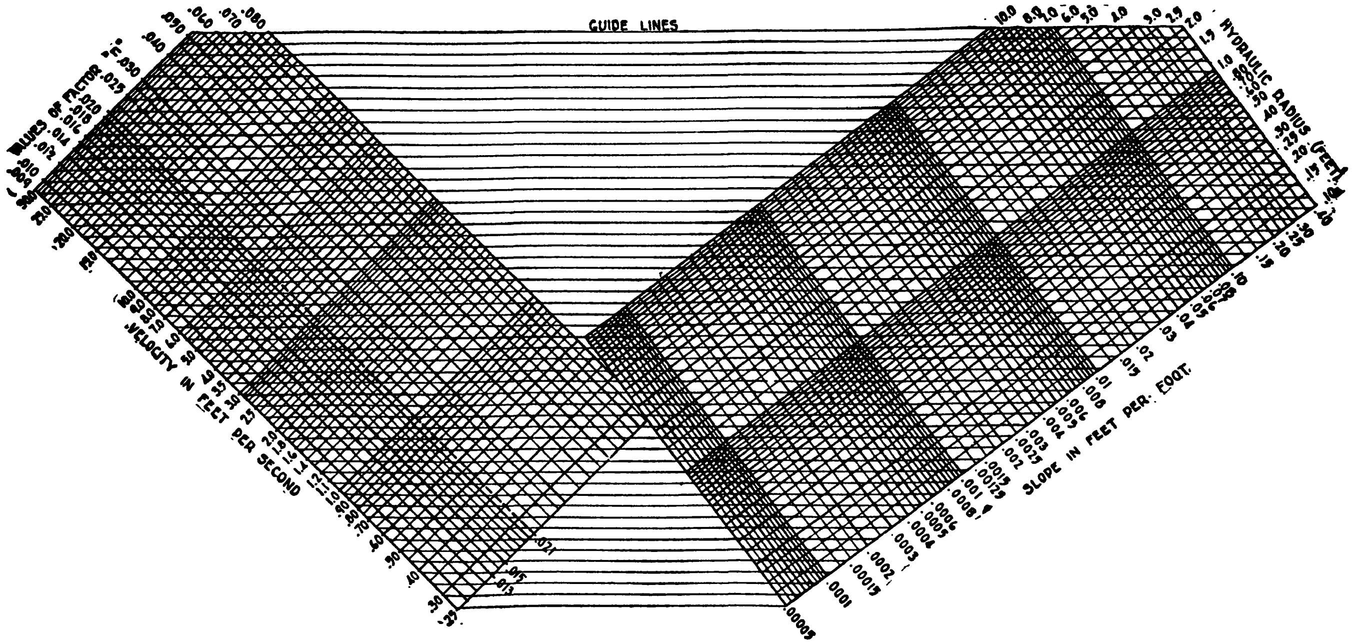


Fig. 162.—Diagram for solution of Manning's formula.

carefully compiled from field observations by a number of investigators over a long period of years. These vary from 0.011 to 0.015 for drain tile and sewer pipe to 0.03 for large drainage ditches in fairly good condition. For crooked natural streams with obstructed channels and for flow over floodways between levees, values of 0.06 and higher have been recorded.

A complete solution of Manning's formula can be approximated from the diagram shown in Fig. 162 by following the directions on the chart.

372. Shape of Channel.—The effect of the channel shape or velocity is measured by the factor R in Manning's formula. A wide, shallow channel is not only better than a narrow, deep one of comparable capacity from the standpoint of machinery operation but also has the property of carrying approximately the same amount and rate of run-off at a lower velocity. This property is illustrated by the following example.

Example.—Assume two channels on a grade of 0.50 feet per 100 feet (0.005 feet per foot), one of which is 3 feet deep with a bottom width of 1 foot and a top width of 7 feet; and the other 1 foot deep, 12 feet wide at the bottom, and 26 feet wide on top. By Manning's formula the velocities and carrying capacities are as follows:

Narrow, deep channel

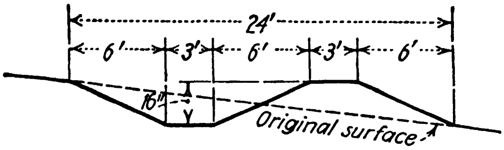
$$\begin{aligned}
a &= 12 \text{ square feet}\\
p &= 9.5 \text{ feet}\\
R &= \frac{a}{p} = \frac{12}{9.5} = 1.26\\
S &= 0.005\\
n &= 0.04\\
V &= (37.15)(1.17)(0.0707)\\
&= 3.07 \text{ feet per second}\\
Q &= aV = (12)(3.07)\\
&= 36.84 \text{ cubic feet per second.}
\end{aligned}$$

Wide, shallow channel

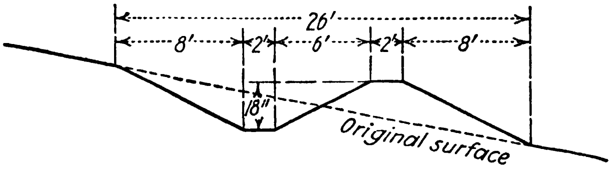
$$\begin{aligned}
a &= 19 \text{ square feet}\\
p &= 26.1 \text{ feet}\\
R &= \frac{a}{p} = \frac{19}{26.1} = 0.73\\
S &= 0.005\\
n &= 0.04\\
V &= (37.15)(0.811)(0.0707)\\
&= 2.13 \text{ feet per second.}\\
Q &= aV = (19)(2.13)\\
&= 40.47 \text{ cubic feet per second}
\end{aligned}$$

Although the deep channel has a cross-sectional area of only 12 square feet as compared with 19 square feet for the shallow one, it can carry almost as much water but at a velocity practically 1 foot per second higher—enough to cause considerable scour. The higher velocity can be accounted for solely by less frictional contact with the water, the wetted perimeter in the first case being 9.5 feet and in the second, 26.1 feet.

373. Dimensions of Cross-section.—The ideal terrace cross-section must have ample capacity to discharge maximum run-off; must be so shaped and laid out as to prevent undue ponding, silting, or scour in the channel; must have embankments low enough and with sufficiently flat side slopes not to impede easy manipulation of farm machinery; must be built so as to disturb as little topsoil as possible and expose the minimum amount of subsoil; and, finally, must be practical to build with available equipment at reasonable cost and efficiency. The dimensions of such a cross-section will necessarily not be the same on a steep as on a flat slope, and a cross-section that fits a particular set of interlocking variables such as soil, spacing, grade, available equipment, etc., will not fit if an appreciable change is encountered in any one. Nevertheless, it is desirable to set up some sort of standard, based on experience, to serve as a general guide, to be departed from when and to the extent that the circumstances of a particular situation may warrant.



For slopes of 2 to 7 per cent, average area of excavation, 7.5 sq. ft.



For slopes of 8 per cent or more, average area of excavation, 9.5 sq. ft.

Fig. 163.—Dimensions of typical terrace cross-sections.

Figure 163 is intended for this purpose.

374. Planning the Layout.—From the foregoing discussion it can readily be seen that proper planning of a terrace layout is a task that calls for considerable ingenuity and resourcefulness. In matters of this kind there is no substitute for practical experience, but sound judgment is at least as dependent upon thorough theoretical understanding.

The first question to be decided is whether the land should be terraced at all. When gathering facts upon which to base a decision, the field should be examined by walking around the boundaries and exploring it from every angle. Outlet possibilities, prevailing degree and regularity of slopes, type and erosive condition of the soil, foreign land, if any, lying above the boundaries, approximate length of terraces required, and the intelligence and interest of the landowner or tenant, are all factors to be carefully weighed and considered.

Terraces are generally inadvisable on cultivated slopes above 15 per cent or on fields so cut up with gullies as to make the expense prohibitive. Thin soil, uniformly eroded, does not necessarily make terracing uneconomical, because terraces buttress and conserve applications of lime, fertilizer, and other soil-building practices that might otherwise be largely wasted. In all cases, however, the cost should be weighed against the probable increase in land value (generally estimated at a minimum of $8 per acre) before adjudging the project feasible. The difficulty and cost of procuring an erosion-proof outlet may also be a limiting factor in some situations. Unless the farmer understands the purpose of terraces, is sold on the idea, and is willing to take extra trouble to insure their proper functioning, it is usually unwise to try to force them upon him prematurely, in spite of the fact that the alternative may be utter ruin within a few years.

If the reconnaissance survey results in a decision to go ahead, it is necessary to select the outlet or outlets to be used and envision a tentative arrangement of the terrace lines (sometimes, on very irregular ground, a topographic map may be necessary before this can be done). The next step is to measure the average slope above each tentative terrace and determine an appropriate spacing. With the spacing decided upon, the lines are ready to be staked out on the ground, beginning with the uppermost terrace and proceeding progressively down the slope. If some special feature exists part way down the hill, such as a sharp break in topography, a rocky point, the head of a large gully, a barn, or other obstacle, the position of a "key" terrace will arbitrarily be fixed and the other terraces must be adjusted to it. The key terrace should be the first one staked out, but, regardless of the order of staking, the uppermost terrace should be *built* first, followed by the others in next lower succession, to guard against the possibility of heavy rains overloading the lower terraces during construction.

Many times the layout could be greatly improved if several neighbors cooperated in a terracing program and thus enabled artificial property lines to be ignored and the best natural arrangement adopted. When this is not possible, and extraneous water is discharged upon the field to be terraced from higher land beyond its borders, such water must be intercepted and carried to an outlet by a different route through a diversion ditch located near the boundary. The grade and dimensions of the ditch can be determined by the methods already described.

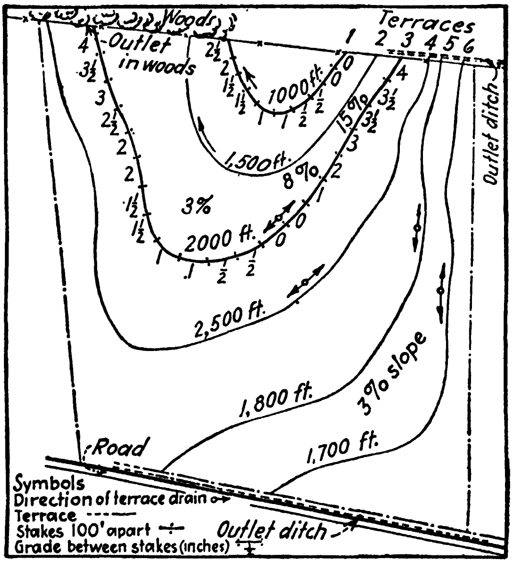


FIG. 164.—Typical terrace layout. (*Alabama Extension Circ.* 148.)

Figure 164 shows a typical layout of terraces with variable grade on sandy loam soil. It is unfortunate that the outlet ditch on steep ground at the northeast corner could not have been avoided, but the length of the fourth terrace (from the summit) made it necessary. Only a relatively small amount of water is drained into it, however. It is always desirable and easier to drain *away* from steep slopes toward flat ones; but where this cannot be done the terrace grade is usually increased somewhat, as shown in the northeast portion of Terrace No. 3. Flow is divided in all terraces except the upper two, which drain away from the steep slope and discharge into dense timber. The northeast outlet ditch will need special protection from erosion. The south outlet ditch, being on flatter slopes, can probably be controlled by vegetation alone. Note that it is constructed inside the fence line to avoid overfalls into the highway side ditch. The water is carried parallel to the road until the velocity is sufficiently reduced to allow discharge into the highway ditch without danger of scour.

375. Surveying Procedure.—For staking out the terrace lines, some kind of leveling instrument is necessary. The simplest device is a wooden A-frame built in the form of a capital A with the crossbar horizontal when the legs are upright on a level surface and with a leg spread of 10 feet, 1 rod, or any other convenient unit. The fall to be given the terrace line is computed for a distance equal to the leg spread, and a block of wood is cut to this thickness and nailed to the end of one leg, increasing its length by that amount. To use the A-frame it is carried to the upper end of the first terrace where the short leg is placed at the point of beginning. Holding the short leg stationary, the long leg is pivoted about it up or down the slope until the crossbar is horizontal as determined by a carpenter's level held or fastened against it. The long leg is now at a point on the terrace line. This point is marked on the ground and the short leg is moved to it, the process being repeated to establish the next point, and so on until the outlet is reached. This procedure is extremely awkward and tedious and requires great care to insure a fair degree of accuracy but may be tried if no better instruments are available.

Without any doubt the best results are secured in the least time from the use of a standard engineer's level and Philadelphia rod in the hands of trained surveyors, but it is equally true that satisfactory work can be done in a practical way by the use of an inexpensive farm level and rod. Popular types of farm levels, illustrated in Chap. IV, may be had complete with rod for about $25. The rod is normally 5 feet long but can be extended to 9.5 feet, is equipped with a target, and is available with optional graduations in feet, inches, and quarter inches or in feet, tenths, and hundredths.

376. Application to Terrace Layout.—Figure 165 illustrates the use of the level and rod in determining the prevailing slope of a field preparatory to selecting the proper spacing for the terraces. If the slope is quite steep the downhill sight for a distance of 100 feet may be clear over the top of the rod, in which case a reading may be taken at 50 feet and the difference multiplied by two.

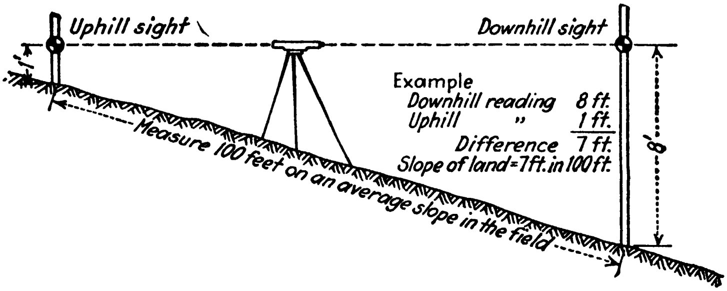


FIG. 165.—Use of level in determining prevailing slope.

With the terrace spacing decided upon, the location of the first terrace below the top of the hill can then be determined as shown in Fig. 166 or by measuring or pacing down the slope the distance equivalent to the vertical drop. So far as practicable, it is desirable to begin at the outlet to stake out the terrace line, the procedure for which is as follows:

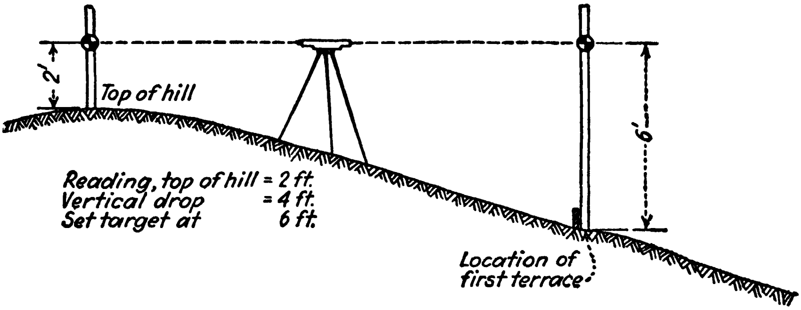


FIG. 166.—Use of level in locating first terrace.

Assuming the downhill rod in Fig. 166 to be at the outlet of the first terrace and that the grade for the lowest 300 feet is to be 4 inches per 100 feet, or 0.33 per cent, the rodman lowers the target 2 inches, or 0.165 foot, and proceeds 50 feet by measuring or pacing in the general direction of the terrace line and holds the rod for a trial reading. The instrumentman focuses on the target, checks the level bubble, and signals the rodman to move up or down the hill until the horizontal cross hair bisects the target. The bottom of the rod at this point is on grade, and its position is marked by a stake. *Caution:* For all readings the rod should be held on "average ground," neither in a local low spot nor on top of a row or clod; this is especially applicable when locating on plowed ground or after harvesting a crop grown in rows.

Having driven a stake on grade at the first 50-foot point, the rodman then lowers the target another 2 inches, or 0.165 feet, proceeds another 50 feet, and goes through the same process as before to locate the grade at this point, driving a stake to mark it. This procedure is repeated until the point is reached where the grade is to be reduced, after which the target setting is adjusted to the new grade and the work continued. When the rodman reaches a point about 250 feet from the instrument, he should drive a stake nearly flush with the ground and use it as a turning point for a new instrument position, as already explained and as illustrated in Fig. 167.

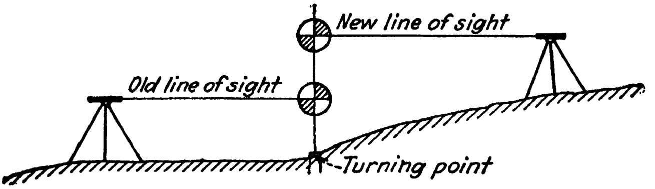


FIG. 167.—Illustrating change of position and determination of new height of instrument from turning point.

It is obvious that, in order to determine a trial grade line and the points where it should change, it is necessary to estimate the terrace length before knowing its exact position. This can be done on fairly uniform slopes closely enough for practical purposes, but, while staking out any terrace, one should be constantly on the lookout for opportunities to improve the location by altering the grade or by making slight shifts in the entire line. It sometimes happens that the upper portions of the line fit the ground so badly as to necessitate abandonment and a complete rerun on a new grade.

Unless the change in direction of the line being staked is gradual enough to permit accurate tracing with a plow or other implement, intermediate stakes should be set at 25-foot points or closer. This is most frequently necessary at gully crossings where the stakes should be set uphill a slight amount off grade, if this does not make the terrace too crooked, in order to provide extra earth for the embankment when cutting the channel to grade. It must be admitted, however, that this practice is seldom feasible, owing to the sharp bend created in the terrace. Good practice in such cases is illustrated by Fig. 169.

When the first terrace has been satisfactorily located, it is customary to return to the outlet, spot the second terrace, as indicated in Fig. 168, and proceed as before with the staking out. This is continued until all the terraces in the field have been located and marked out on the ground ready for construction.

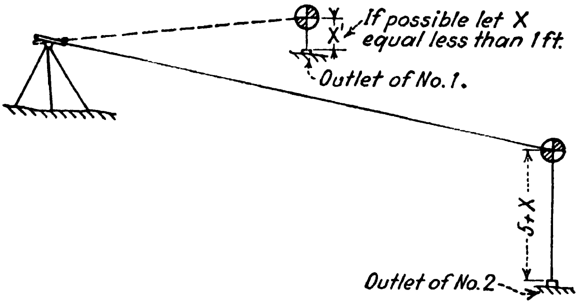


FIG. 168.—Use of level in locating second terrace.

It is convenient but not necessary to mark the station numbers on the stakes of each terrace indicating distance from the outlet. Thus, the outlet stake would be marked 0 + 00, and then in successive order, 0 + 50, 1 + 00, 1 + 50, 2 + 00, etc., each "station" or whole number representing 100 feet and the "pluses" fractional distances less than 100 feet. When some time will elapse before the terraces are constructed, it is very desirable to follow this practice, marking the terrace number or letter on each stake in addition to the station number.

377. Construction Methods.—After the terrace lines have been located by means of stakes or markers at normal intervals of 50 feet, it becomes necessary to trace out each line between the stakes, around peninsular points, and across gullies. This can best be done by having someone of experience and with a "trained eye" walk slowly ahead of the plow or other marking implement and indicate the direction of the line between stakes so as to smooth out minor irregularities and maintain the intended grade throughout. The driver of the power unit follows close behind and lays his course on the "pilot," being especially careful to swing wide in going around points and, if practicable, in crossing gullies. Should the gully center line lie in a depression of appreciable width, a mathematically correct grade forms an apex too sharp and narrow for construction machinery to follow, in which case the only practicable procedure is indicated in Fig. 169. Extra work will be required to build the embankment up

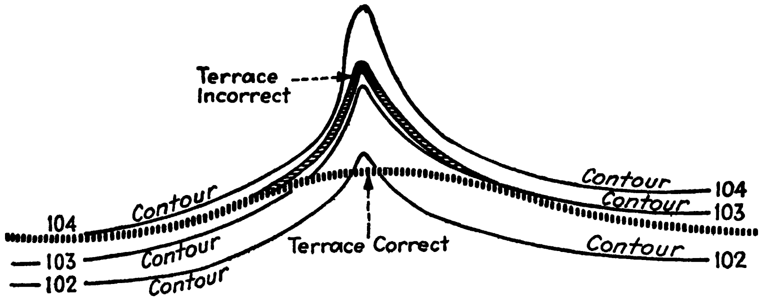


FIG. 169.—Sketch indicating practicable crossing of gullies in wide depressions.

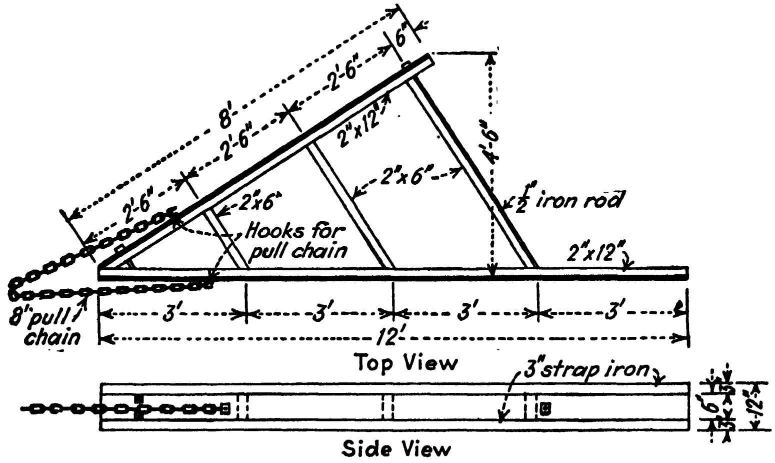


FIG. 170.—Homemade wooden V-drag for use in building terraces.

Bill of Materials

1—2" × 12" × 12' − 0"
1—2" × 12" × 8' − 0"
1—2" × 6" × 14' − 0"
1—½" ϕ iron rod—5' − 2" (head at one end thread and nut at other)

2—½" × 5" bolts
4—⅜" × 2½" bolts
2 hooks
2 pieces 3" strap iron 8' − 0" long
2 pieces 3" strap iron 12' − 0" long

to grade at such locations, and a temporary water pocket will appear in the terrace channel.

Construction Details.—There are almost as many ideas regarding precisely the best procedure in building terraces as there are people engaged in this work. While the controlling factors are type and condition of soil and soil cover, prevailing land slope, and equipment used, there is ample opportunity for considerable variation within these limits to accord with individual preferences. Inexperienced operators will soon form their own preferences after making a few trial runs with the most efficient equipment available.

It is possible to build terraces by making many trips with a common walking plow with or without a special moldboard attachment, by continually backfurrowing to the terrace bank. A slip scraper to pile the loosened earth into the embankment speeds up the process considerably and is popular in a few localities. If the cash outlay for purchase or rental of equipment must be kept to an absolute minimum, fairly efficient work can be done with a homemade V-drag built of wood according to the drawing shown in Fig. 170, or a reversible steel V-drag or ditcher can be bought at moderate cost. The dimensions of the drag can be varied to suit the number of horses or mules used and the kind of soil encountered, in accordance with Table 34.

TABLE 34.—DIMENSIONS FOR HOMEMADE V-DRAG

	Number of horses or mules				
	2	3	4	6	8
Length of short wing, feet	4½	5	6½	7	8
Length of long wing, feet	8	9	11½	12½	14
Size of material for wings, inches	2 by 8	2 by 10	2 by 12	2 by 12	2 by 12
Spread between wings for black land (33°)	2½′	3′	3½′	4′	4′ 4″
Spread between wings for sandy land three-fifths of length of short wing (37°)	2½′	3′	3′ 11″	4′ 6″	4′ 10″

[1] *A, & M. Coll. of Tex. Ext. Bull.* B 51.

Figure 171 shows the construction procedure in building terraces in Alabama with horse-drawn equipment. This method was devised by M. L. Nichols and has been used extensively with much success. Each step in the process is clearly shown by the drawing and accompanying notes.

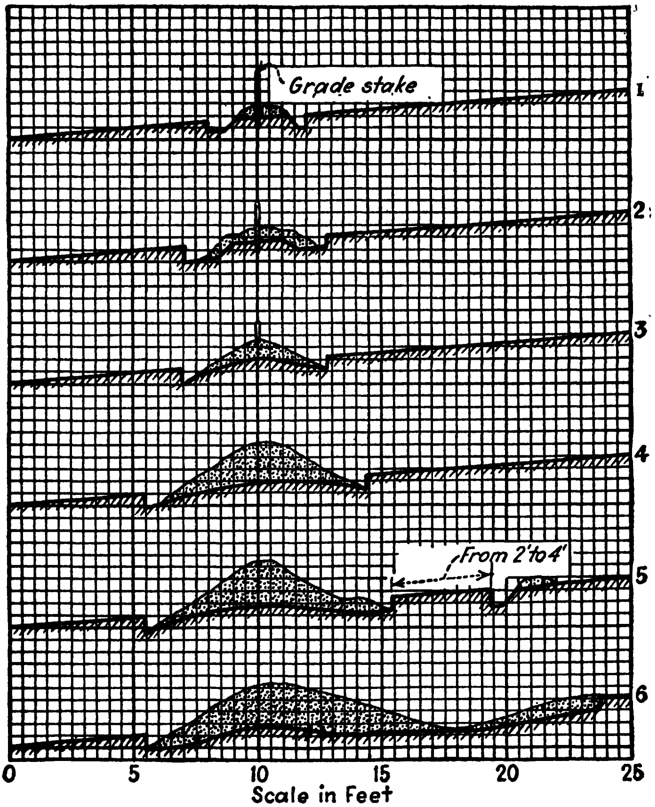
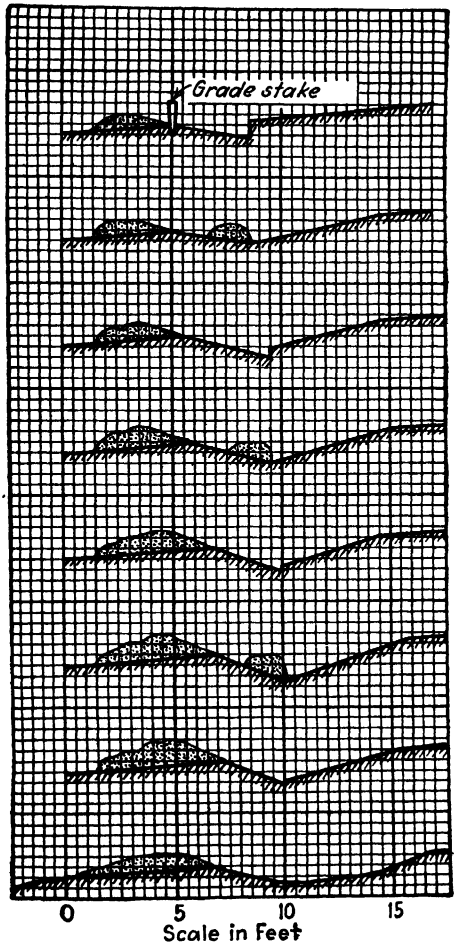


Fig. 171.—Constructing terrace from both sides with horse-drawn plow and V-drag. Throw the first furrow up the hill on the stakes. Four furrows should be thrown to the stakes before the drag is started. Narrow plow cuts should be made and followed with the drag to insure a height of 18 to 20 inches before widening the terrace. The plowing and dragging should be repeated until a width of 8 to 10 feet is obtained. The next step in construction is the laying out of a balk 2 to 4 feet wide on the upper side of the terrace. In plowing out this balk above the terrace ridge, deep narrow plow cuts should be made on the upper side of the balk. Plowing and dragging on both sides of the balk should continue until the entire balk is plowed and dragged out. (*Alabama Extension Circ.* 148.)

One method of building terraces with a blade grader working from the upper side only is illustrated in Fig. 172. This method is featured by making the first cut so as to place the completed embankment over the line and grade stakes, and by the assumption that the field will be plowed and cultivated so as to leave a dead furrow in the terrace channel and gradually increase its capacity.

Figures 173 and 174 illustrate conventional methods of using blade graders where it is desired to make the first cut so that the stake line falls in the completed channel. The terrace in Fig. 173 is built from both sides and the one in Fig. 174 from the upper side only.



First cut, throwing earth downhill 4 or 5 feet below stakes.

Second cut, sloping upper side of ditch, throwing earth in ditch.

Third cut, cleaning ditch and cutting additional depth.

Fourth cut, sloping upper side of ditch, throwing earth into ditch.

Fifth, cleaning ditch and cutting additional depth.

Sixth, sloping upper side of ditch and throwing earth into ditch.

Seventh, cleaning out ditch—the completed terrace.

Cross-section of same terrace after two years' maintenance with two-horse turn plow.

FIG. 172.—Constructing terrace from upper side only with blade grader. Note that grade stake is under embankment and channel is completed during maintenance.

The angle the blade makes with the line of travel is adjustable on all graders and should be as flat as possible and still insure scouring of the soil against the blade. Sharper angles are usually required for clay than for sandy loam, and for cut trips in any soil as compared with carry-over trips.

All graders are also provided with means of adjusting the depth of either end of the blade, and the depth of the cutting edge should be kept regulated so as to utilize the full capacity of the grader and power unit at all times. There should, of course, be a close relation between the sturdiness and weight of the grader and the capacity of the power unit with which it is used.

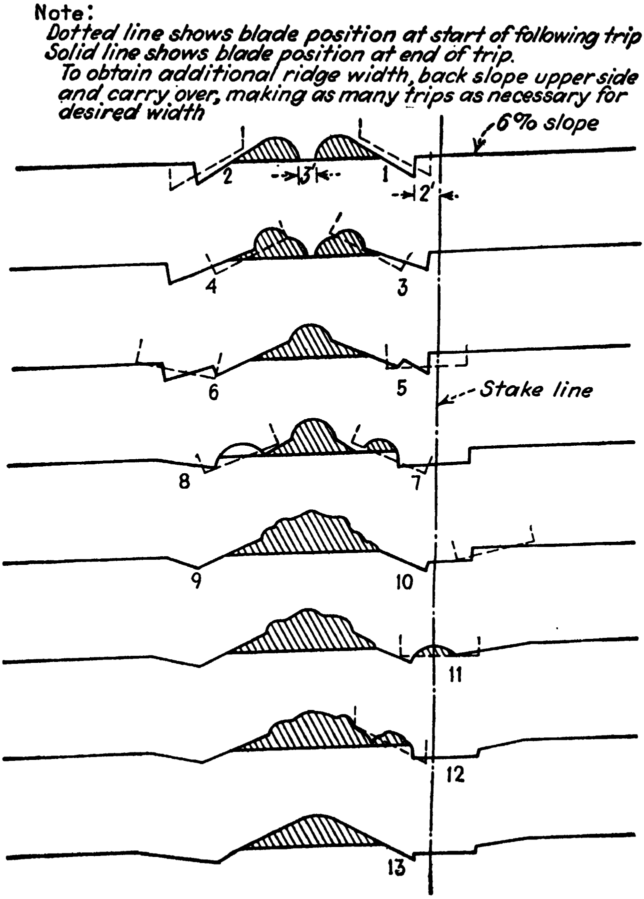

Note:
Dotted line shows blade position at start of following trip
Solid line shows blade position at end of trip.
To obtain additional ridge width, back slope upper side and carry over, making as many trips as necessary for desired width
6% slope
2
3'
1
2'
4
3
6
5
Stake line
8
7
9
10
11
12
13

FIG. 173.—Method of constructing terraces with 10-foot blade grader working from both sides. Land slope 6 per cent.

A diagrammatic representation of the technique of building terraces with a Whirlwind rotary terracer is shown in Fig. 175.

This machine, which embodies an entirely new principle of moving earth, is of very recent development but already has been used in such varied states as Iowa, Kansas, Missouri, Illinois, Mississippi, Georgia, the Carolinas, and Oklahoma. It will be described later.

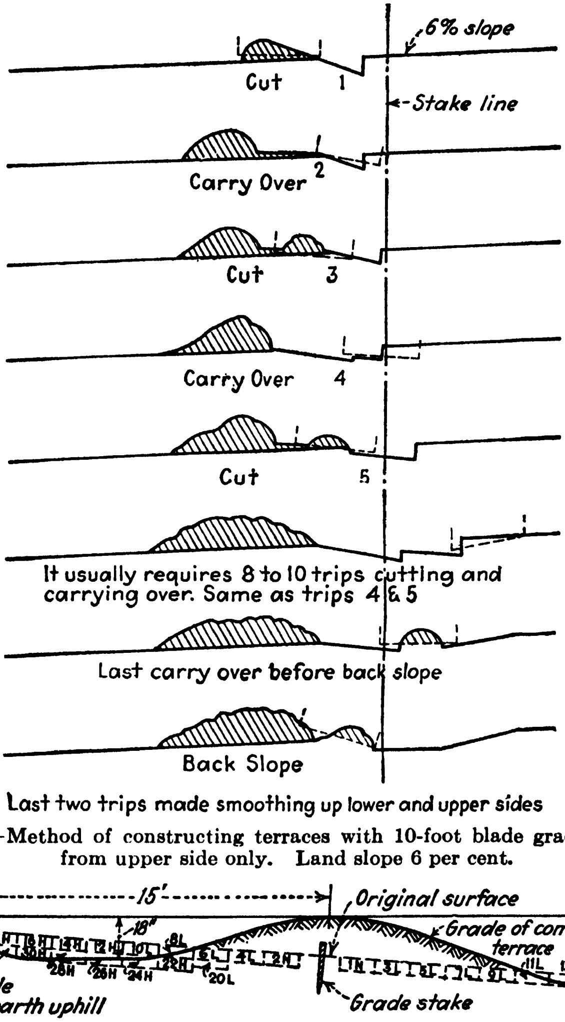

6% slope
Stake line
Cut 1
Carry Over 2
Cut 3
Carry Over 4
Cut 5
It usually requires 8 to 10 trips cutting and carrying over. Same as trips 4 & 5
Last carry over before back slope
Back Slope
Last two trips made smoothing up lower and upper sides

FIG. 174.—Method of constructing terraces with 10-foot blade grader working from upper side only. Land slope 6 per cent.

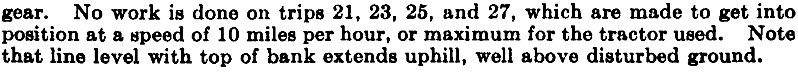


FIG. 175.—Diagram illustrating technique of building terraces with a Whirlwind rotary terracer. Numerals represent trips one way and the order in which furrows are made. Letters indicate rotor speed: *N*, neutral; *L*, low gear; *H*, high gear. No work is done on trips 21, 23, 25, and 27, which are made to get into position at a speed of 10 miles per hour, or maximum for the tractor used. Note that line level with top of bank extends uphill, well above disturbed ground.

378. Construction Equipment.—Aside from common farm implements and special homemade devices a great variety of equipment has been commercially developed to meet the terracing demands of various situations. Especially marked has been the activity in this field under the impetus of various federal emergency conservation programs, most of the effort until recently being directed toward the adaptation of machinery originally designed for use on highways, principally blade graders. Inasmuch as terrace building is a specialized job of limited extent so far as any one farm is concerned, the cost of the most efficient equipment of this type ($4,000 for tractor and grader) is prohibitive unless some means of community financing is worked out. Practically every conceivable form of financing has been or is being tried, whether it be custom building by straight contract; by rental from the manufacturer or dealer or from governmental units such as the county; or by joint ownership through the organization of local conservation associations. Occasionally title to enough land in need of terracing is held by a single owner or mortgage company to justify the purchase of efficient machinery. Whatever the method of financing, the object is to make available the low operating cost and rapid progress of efficient equipment by spreading the overhead over a large number of jobs.

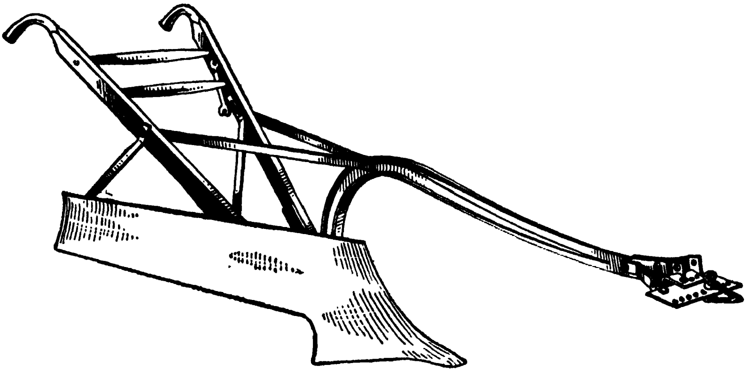


Fig. 176.—A popular and economical type of terracing plow. (*Courtesy of G. A. Kelly Plow Company.*)

Terrace building by such methods has the disadvantage of leaving the farmer without means of cleaning out the terrace channel and maintaining the height of the bank, but this is not a valid objection since it has been demonstrated that the demands of reasonable maintenance can be met satisfactorily by proper cultivation with ordinary implements. Or, at worst, an inexpensive V-drag can be constructed for the purpose.

The following illustrations are arranged to give a good idea of the implement and power combinations that have been and are being used for terrace building.

379. Terracing Plows.—A popular type of plow that can be equipped for terrace building by attaching a special moldboard is illustrated in Fig. 176. The fact that this plow can be used for ordinary farm purposes when not needed for terracing, by a simple exchange of moldboards, makes it a very economical implement.

380. Steel V-drags.—Figure 177 illustrates a terrace being built entirely from the upper side with four horses and a reversible steel V-drag (Martin ditcher). In soil of ordinary tilth, advance plowing is not necessary with this implement, the wing angle of which is adjustable to suit variations in soil.

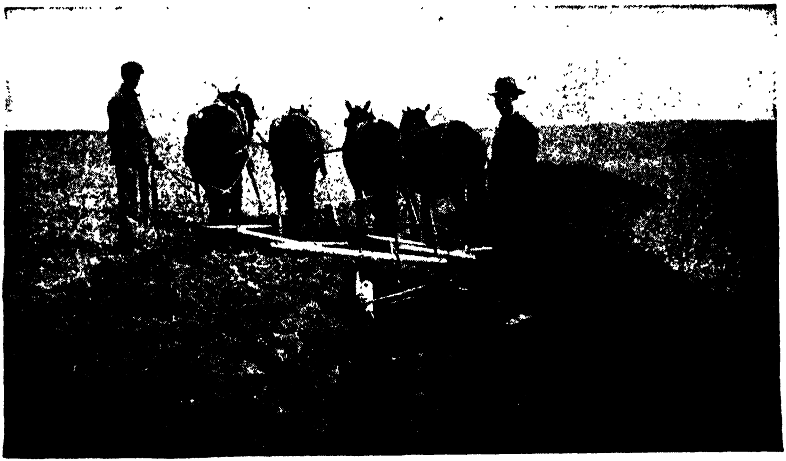


FIG. 177.—Terrace under construction with four horses and reversible steel V-drag.

Figure 178 depicts the same implement equipped with a detachable 2- by 6-inch extension arm being used with tractor power. The cost of this implement is less than $100.

381. Light Terracing Graders.—Two types of small graders especially designed for building terraces and which have been used extensively are shown in Figs. 179 and 180. They may be used with either horse or tractor power.

Very recently another type of small grader has been put on the market. It is illustrated in Fig. 181 where the construction features are clearly shown. This machine is made in two sizes: No. 1 with 6-foot blade and weight of 775 pounds; and No. 2 with 8-foot blade and weight of 825 pounds. In designing this terracer it was the aim of the manufacturers to produce a machine of sufficient strength to utilize all the power of farm tractors, whether crawler or wheel type, and also to keep the price within reach of individual buyers (about $160).

FIG. 178.—Terrace building with steel V-drag (Martin ditcher) and tractor. Note detachable arm to extend point of delivery to top of terrace bank.

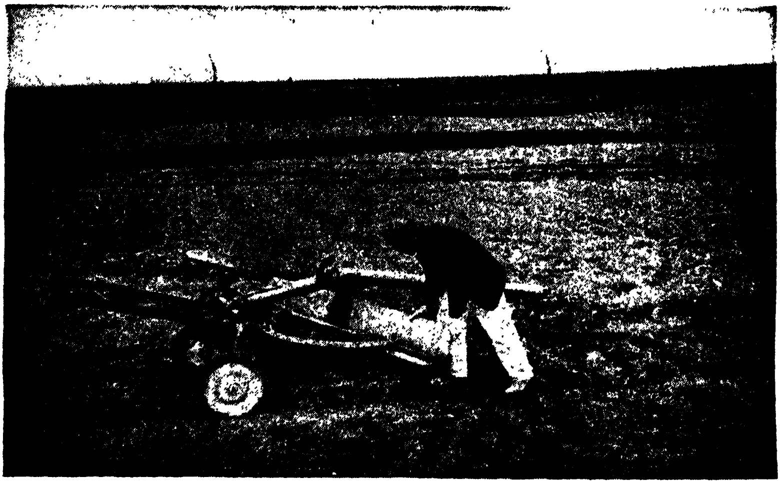


FIG. 179.—Texas terracer designed for use with either horse or tractor power.

On all three implements the front wheel is intended to insure better control of the blade and make the cutting end less sensitive to surface irregularities than it would be if hitched directly to a tractor, as is the case with the two-wheel graders to be described later. When so hitched it is difficult to manipulate the blade so as to cut lightly in depressions and deeply through ridges, which is desirable. What seems to be needed is a system of compensating levers to raise the blade automatically when the rear of the tractor is low and lower it when the tractor is high. So far as the authors are aware no such device has ever been tried.

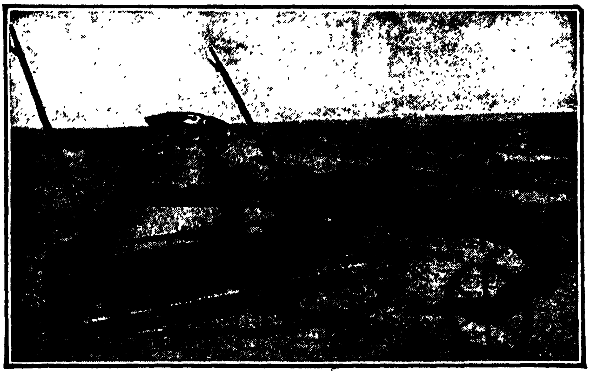


Fig. 180.—Corsicana terracer or ditcher. (*Courtesy of Corsicana Ditcher and Grader Company.*)

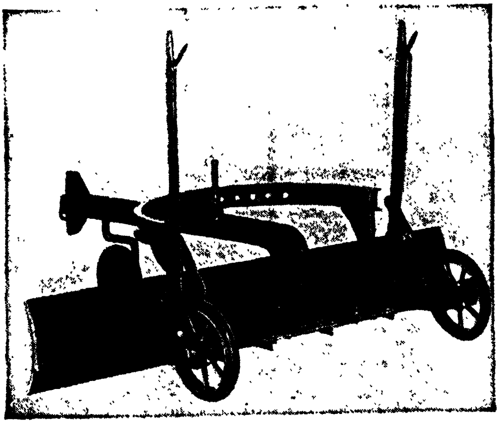


Fig. 181.—New type of light terracing grader. Note the platform upon which the operator stands. (*Courtesy of American Steel Scraper Company.*)

The use of a Corsicana terracer with animal power is illustrated in Fig. 182, and Fig. 183 shows a Texas terracer being pulled with a farm tractor.

382. Four-wheel Graders.—It often happens that four-wheel graders can be rented from county authorities during times when they are not needed for road work; and where land slopes are not too steep or irregular, good work can be expected.

Fig. 182.—Use of Corsicana terracer with animal power.

Fig. 183.—Use of Texas terracer with tractor power.

Figures 184 and 185 represent terraces under construction with two four-wheel graders widely different in style, weight, and power requirements.

383. Special Terracing Graders.—The accelerated demand for terracing incident to various emergency conservation programs beginning in 1933 has been sufficient to attract the interest of machinery manufacturers, who have developed efficient power machinery especially adapted for terrace building. A practical and efficient combination is a two-wheel, 4,500-pound, 10-foot blade grader pulled by a 35- to 40-horsepower Diesel tractor. If

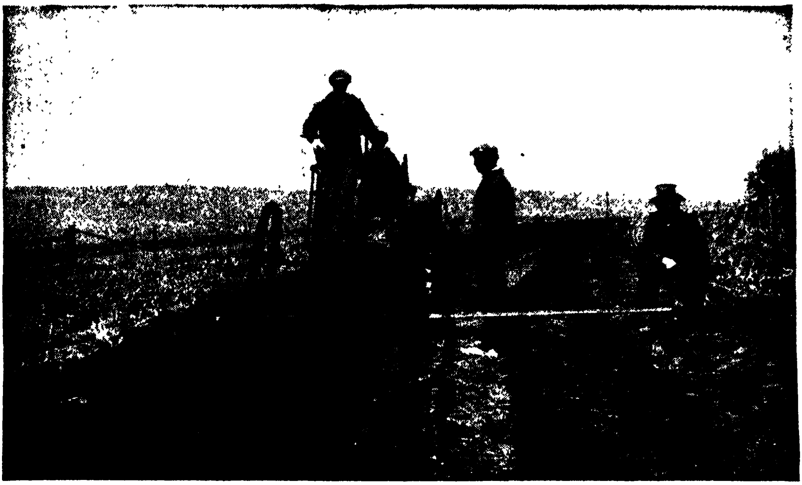


FIG. 184.—Terrace constructed from upper side with light, four-wheel road grader and farm tractor.

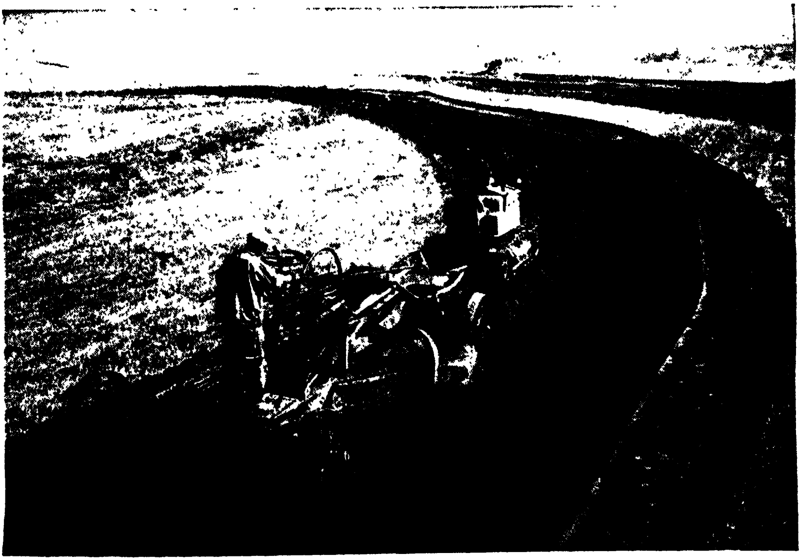


FIG. 185.—Terrace under construction with "regular" road grader and 35-horsepower tractor. (*Courtesy of Austin-Western Road Machinery Company.*)

the first cost, approximating $4,000, can be raised, this outfit can build terraces at surprisingly low operating cost, the fuel consumption being only 1½ to 2 gallons of low-priced (6 cents per gallon) Diesel fuel per hour.

Figure 186 illustrates a less expensive combination consisting of a 22-horsepower tractor and two-wheel, 1,400-pound, 8-foot blade grader. In the illustration the grader is apparently too light for the dry, hard, yellow clay in which it is working, as evidenced by the tendency to slip sidewise.

FIG. 186.—Two-wheel, 1,400-pound, 8-foot blade grader with 22-horsepower tractor working in dry, hard yellow clay. (*Courtesy of Caterpillar Tractor Company.*)

Figure 187 depicts a 40-horsepower Diesel tractor pulling a two-wheel, 4,500-pound, 10-foot blade grader made by the same manufacturer, which seems to be of a power and weight better suited to the job. The operators in this case are boys from a CCC camp in Illinois.

Figure 188 is an outfit of approximately the same weight and power building a terrace in sandy loam soil of the South. This soil is in ideal condition to be moved with a blade grader.

Such equipment as that illustrated in Figs. 186, 187, and 188 has been designed especially for easy manipulation and mobility in building terraces under ordinary farm conditions. The blade is easily reversible, and quick turns can be made in a limited space at the terrace ends. Figures 187 and 188 illustrate types of equipment that are undoubtedly economical and practicable terracing outfits, subject only to limitations inherent in the blade method of moving earth and to the fact that special tractors

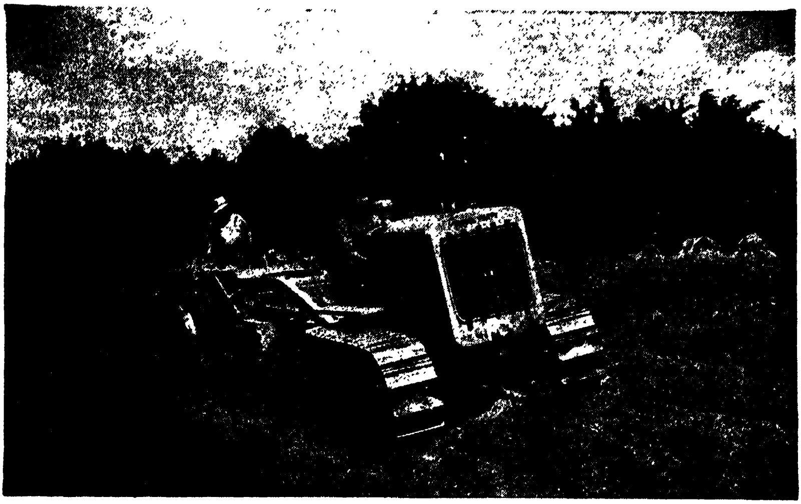


Fig. 187.—Two-wheel, 4,500-pound, 10-foot blade grader with 40-horsepower Diesel tractor building terraces in Illinois. (*Courtesy of Caterpillar Tractor Company.*)

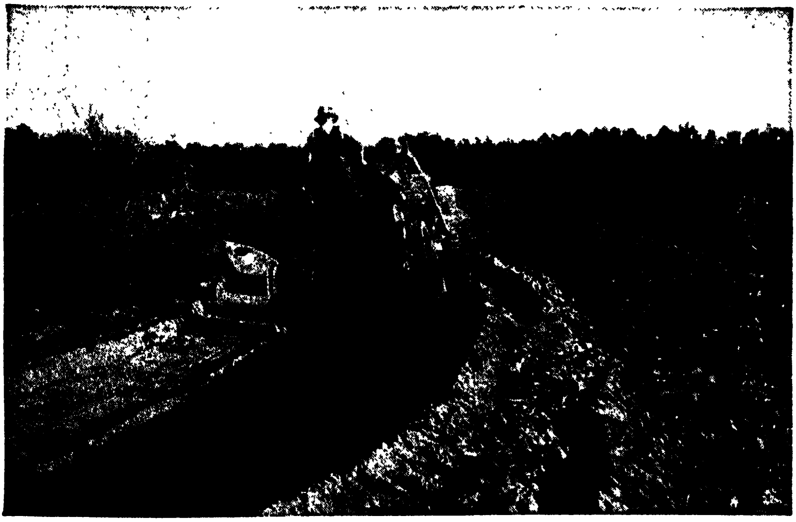


Fig. 188.—Building a terrace from the upper side in sandy loam soil with a two-wheel, 4,500-lb., 10-foot blade grader and 35–40-horsepower tractor. (*Courtesy of Austin-Western Road Machinery Company.*)

are required that are not adapted to the needs of routine farm jobs.

384. Heavy Elevating Graders.—On large farms of the Southwest with regular slopes of moderate declivity, the heavy equipment shown in Fig. 189 has been used with considerable economy and success. Elevating graders of this class are operated with a separate power unit mounted on the grader and are equipped with a short carrier especially designed for terracing. The best work is done with a 75-horsepower tractor to provide power for pulling and plowing. After three to five round trips with the elevating grader the terrace is finished in two or more rounds with a 12-foot blade grader and 50-horsepower tractor. This kind of construction has the advantage of placing a minimum amount of topsoil in the terrace core, and where a large amount of terracing is to be done under the special conditions mentioned the unit cost can be kept very low. The technique of using equipment of this kind is illustrated in Fig. 190. This is not included in the discussion of ordinary terrace-building technique because of its special nature.

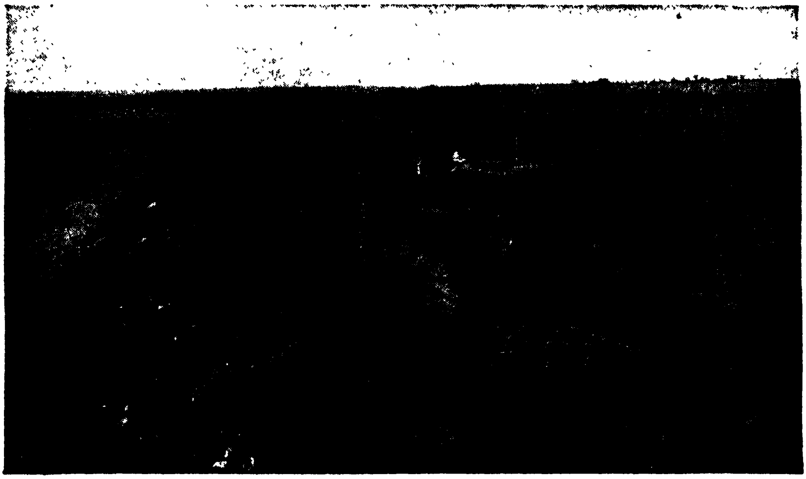


FIG. 189.—Large elevating grader and 50-horsepower tractor building terrace core in Kansas. (*Courtesy of Caterpillar Tractor Company.*)

After the main fill of 0.50 to 0.75 cubic yards per lineal foot of terrace has been completed with the elevating grader, and the 12-foot blade grader has back-sloped the furrows and distributed topsoil over the terrace, it is customary to smooth out irregularities and prepare for seeding by the use of a 50-horsepower tractor pulling three heavy disc harrows. One round with this outfit

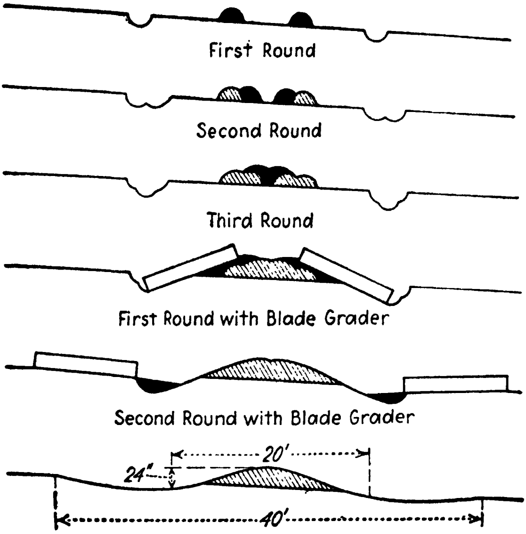


FIG. 190.—Technique of building terraces. This drawing outlines the procedure used in building 40-foot terraces with a 50- or 75-horsepower Diesel tractor pulling the elevating grader, followed by a 50-horsepower Diesel tractor pulling a 12-foot blade. On a 156-mile check run at Mankato, Kan., the total cost, including all items, for building the core and blading in the balance of the terrace with this Diesel power was only $16.04 per mile. The cost of these two operations, exclusive of fresno work and transportation, was only $.87 per acre, which is a real record for building terraces of this type.

FIG. 191.—Fifty-horsepower tractor and three 10-foot sections of heavy disc harrows smoothing out irregularities in elevating grader-built terraces and preparing them for seeding. (*Courtesy of Caterpillar Tractor Company.*)

of 30 feet of discs, which is illustrated in Fig. 191, is said to leave the field so no water will collect in low spots.

Where conditions are suitable for this class of equipment, it may be remarked in passing that a modification of the familiar template or bucket excavator might very possibly complete a terrace in one trip with the greatest economy of all.

385. Light Elevating Grader.—The small elevating grader shown in Fig. 192 was designed by J. C. Wooley of Missouri especially for terracing and allied work. As can be seen from the photograph, it is equipped with a 26-inch disc plow to deliver the earth to a belt conveyor that is operated from the power take-off of the tractor. It is intended for use with general-purpose farm tractors and is popular in some localities. The usual construction technique consists in plowing along the line of stakes and moving the earth downhill, the return cut being made just below the soil deposited from the first cut. The two rows of soil thus deposited outline the lower and upper edges of the terrace embankment and the cuts in additional rounds are so made as to fill in the interspace two furrows deep. By skillful manipulation, including variable depths of end cuts, a uniformly shaped terrace results; but a channel of appreciable size is inevitable on the downhill side. Ten to twelve rounds or more are required for an embankment 20 feet wide and 18 inches high

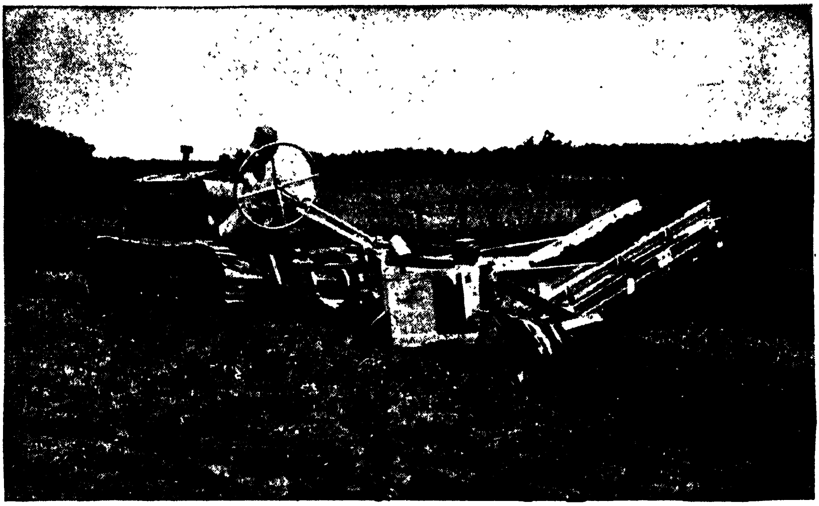


FIG. 192.—Light elevating grader building terraces with tractor. (*Courtesy of Cleveland Tractor Company.*)

when soil conditions are just right. It is to be noted that the machine is designed for one-man operation, the entire mechanism being under control of the tractor driver.

Advantages claimed for this type of terracer are: (1) it will work in any soil in which a disc plow will operate, (2) it has the light draft and the rolling, slicing action found in a disc plow, and (3) it has greater capacity with less power (compared with blade graders) as it moves the earth horizontally on a free rolling belt. Another advantage lies in its ability to form an embankment approximating a uniform height when crossing low spots by reason of delayed delivery of a given plow cut occasioned by the time required for the earth to travel up the belt. This same feature, however, entails more finishing work at the terrace extremities. The cost of the elevating grader-terracer is about $950 in Kansas City, Mo.

386. Multiple-disc Plow.—As shown by the illustrations in Figs. 193 and 194, it is possible to construct terraces by the use of a multiple-disc plow and general-purpose farm tractor. However, so far as the authors are aware, this implement has not, as yet, come into extensive use for building terraces. Terraces so constructed would have the advantage of being ready for seeding without additional preparation. The artist's sketch represented

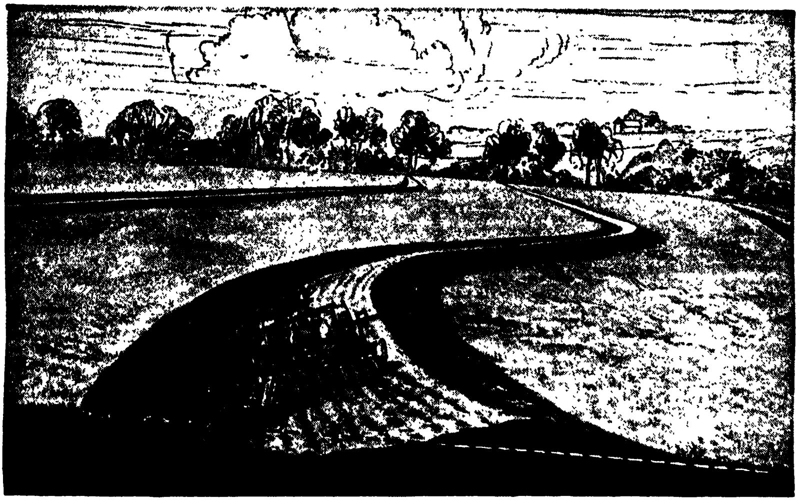


FIG. 193.—Artist's sketch showing terraces under construction with a multiple-disc plow and the relation of a terrace system to the general landscape. (*Courtesy of J. I. Case Company.*)

by Fig. 193 is included for its value in clearly showing the dimensions and proportions of a typical terrace and the relation of a terrace system to the general landscape.

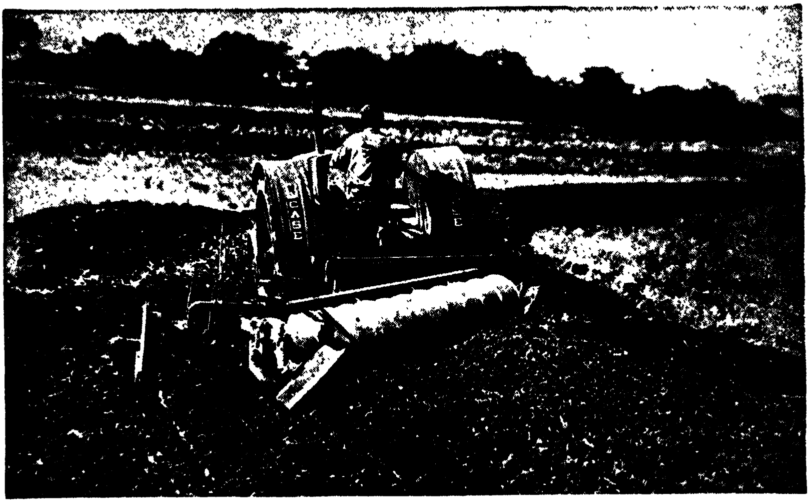


Fig. 194.—Photograph of a multiple-disc plow building a terrace. (*Courtesy of J. I. Case Company.*)

387. Whirlwind Rotary Terracer.—One of the promising machines being developed for building terraces is the invention of E. V. Collins of Iowa, the idea for which came to him while experimenting with a machine for killing white grubs. This light and simple but effective machine is shown by Fig. 195 to consist essentially of an 18-inch plow with modified moldboard to deliver

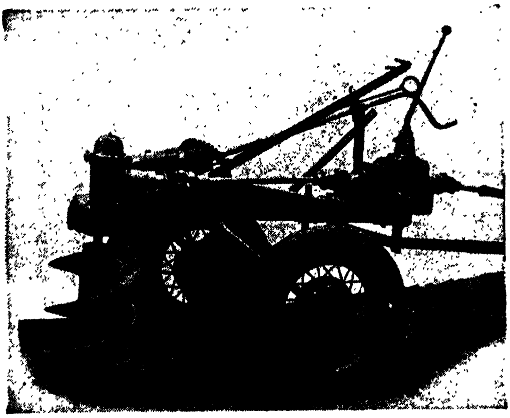


Fig. 195.—Side view of Whirlwind rotary terracer.

the earth to a 14-inch spiral-bladed rotor, a transmission gearbox controlling the rotor speed, power take-off connections to the tractor, and a sturdy frame supported on two pneumatic-tired wheels. Figure 196 shows the earth being thrown or "sprayed" in a sidewise direction, the length and density of the fan being regulated by the pitch of the blades and the speed of the rotor. The machine is characterized by extreme mobility and operates on the principle of placing a relatively small quantity of earth during each trip, making up in speed, both of transit and in turning at the ends, what it lacks in unit capacity. The operating technique in forming terraces has already been pointed out in Fig. 175.

Fig. 196.—Whirlwind rotary terracer in action.

Like the steel V-drags, light graders, and other equipment described, the rotary terracer can be used with an ordinary farm tractor and its cost (about $550) is not beyond the purchasing power of a neighborhood group of farmers. Should experience prove the need, the machine could be made reversible by the use of a duplicate rotor and special reversible plowshare.

388. Completion and Checking of Terrace Grades.—Aside from the construction of terrace outlets where none exist naturally, there is usually a considerable amount of unavoidable clean-up work in bringing the embankments to grade at gully crossings and other low areas, dressing up the terrace at its outlet junction, and smoothing out appreciable irregularities. While it is seldom practicable or necessary to dress the channel to its exact theoretical grade, it is desirable to run a line of check levels before the construction equipment leaves the field so that back cuts can be made where necessary to bring about reasonable drainage. Figure 197 shows a system of newly constructed terraces after a light rain, which is quite typical of the amount of ponding to expect before the clean-up work is finished.

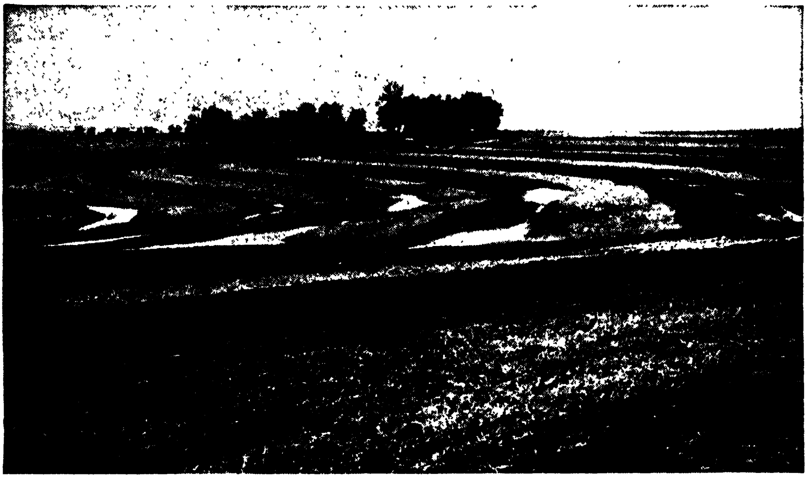


FIG. 197.—System of newly constructed terraces after a light rain showing amount of ponding to expect before clean-up work is complete.

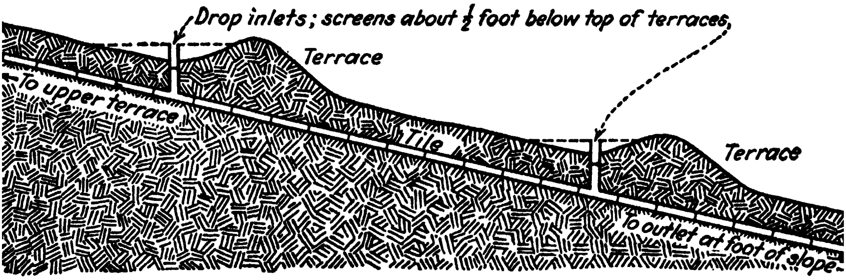

Drop inlets; screens about ½ foot below top of terraces
Terrace
To upper terrace
Tile
Terrace
To outlet at foot of slope

FIG. 198.—Method of removing water standing above terraces in a gully or draw. Also used as outlet for level terraces.

If the depth of the ponds formed at gully crossings is excessive or if the ponds are otherwise objectionable, they can be drained under the terraces through a line of tile laid down the slope, as indicated in Fig. 198.

A conventional method of building up low places in the bank with a team of mules or horses, one man, and a slip scraper is shown in Fig. 199; and Fig. 200 shows the same kind of work under way with power equipment.

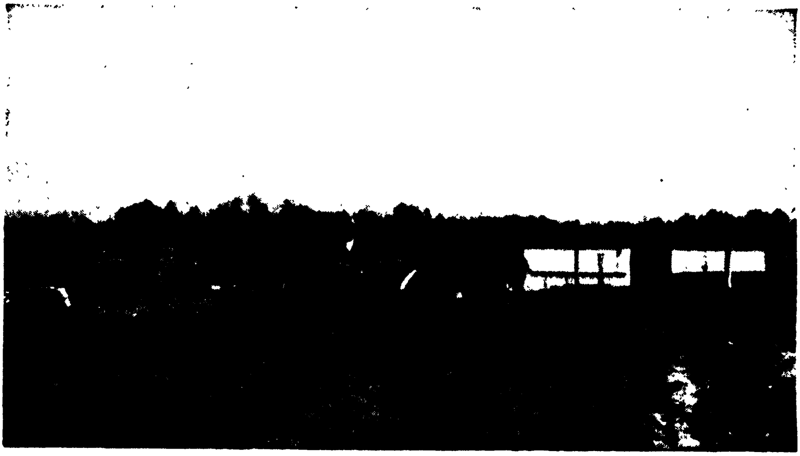


FIG. 199.—Building up a low place in a terrace embankment with a team of mules, one man, and a slip scraper.

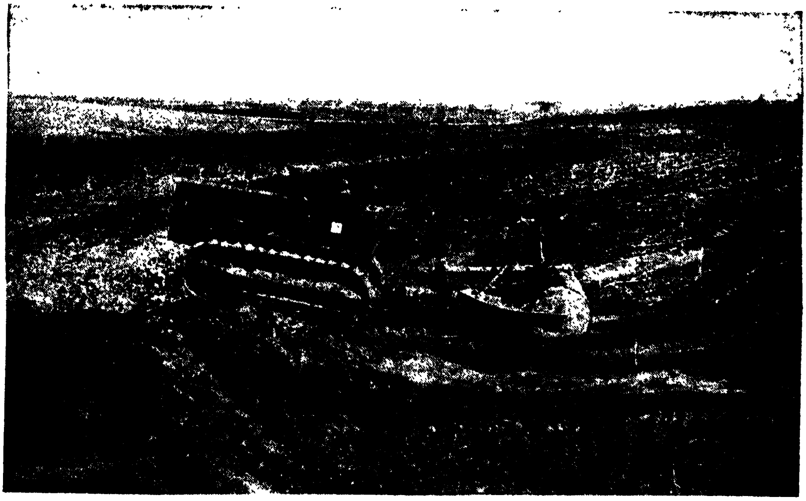


FIG. 200.—Filling low spot in terrace embankment with tractor and fresno rotary scraper.

389. Terrace Construction Costs.—From the foregoing it is evident that the cost of terracing is necessarily quite variable and is dependent upon numerous factors, chief among which are:

Texture and condition of soil, and kind of cover.
Prevailing degree and regularity of slopes.
Extent of erosion at time work is done.
Availability of erosion-proof natural outlets.
Kind of implements used.
Kind of power used to operate implements.
Dimensions of terrace channel and embankment.
Length of terraces, which determines time consumed in turning at ends.
Experience and skill of operators, and technique of building.
Manner in which work is financed.

No true and complete comparison of cost data is possible unless each of these factors is fully known and evaluated but, since no two have precisely the same weight and some are much more influential than others, comparisons close enough for practical purposes may be had when approximate conditions are given.

In *U. S. Department of Agriculture Bulletin* 1669, Ramser suggests minimum costs for light equipment working under favorable conditions as to soil, slope, and terrace length as indicated in Table 35. These costs are based on the use of steel ditchers or terracers of the V-shape or grader type, using local power.

TABLE 35.—APPROXIMATE COSTS OF CONSTRUCTING TERRACES 15 INCHES HIGH, 20 FEET WIDE, AND NOT LESS THAN 1,000 FEET LONG, IN LIGHT SOILS ON MODERATE LAND SLOPES

Description of land	Cost per acre	Remarks
Clean-cultivated land, no gullies....	$1.50 to $ 2.50	
Grass or virgin land, no gullies......	2.00 to 3.00	
Clean-cultivated land, small shallow low gullies.	3.00 to 6.00	Depending upon the number of gullies
Clean-cultivated land, gullies 3 to 6 feet deep.	7.00 to 15.00	Depending upon the number of gullies
Newly cleared land, no gullies, most stumps grubbed out.	7.00 to 12.00	Depending upon the kind and number of roots and stumps

Where the labor and power are paid for in cash, substitution of a homemade wooden drag would increase the cost 25 to 40 per cent.

According to Hamilton in *U. S. Department of Agriculture Farmers' Bulletin* 1789:

> Since there are so many variables affecting the cost of terrace construction it is very difficult to compare costs from different areas. Table 36 gives terracing costs at a number of the Soil Conservation

Service demonstration projects. Costs on performance of different types of terracing equipment after as many of the variables as possible have been eliminated are given for individual States and groups of States. The equipment rates were determined by using the average costs submitted by the projects for the various types of equipment. An operator's average wage of 37 cents per hour was used, and only the time and cost actually necessary to construct the terrace were included. No lost time, supplemental fill work, or outlet work was considered. The costs shown for these States indicate the cost of terracing with equipment that is representative within the several States. The table also shows the terracing cost in four regions of the Soil Conservation Service. The types of equipment used were somewhat similar to the types used in the States. These costs include the actual rates submitted from the field, lost time, and repairs. Staking, supervision, fill work, outlet work, and overhead are not included.

TABLE 36.—AVERAGE COST OF TERRACE CONSTRUCTION ON SOIL CONSERVATION SERVICE DEMONSTRATION PROJECTS

State or region	Power of tractor	Terracer	Average slope, per cent	Terraces constructed, miles	Earth per mile, cubic yards	Time worked, hours	Total cost per mile	Cost per cubic yard
	Plow							
Illinois, Iowa, Missouri	3 to 4	Rotary	3-8	19.2	1,984	615.6	$32.06	$0 016
Iowa, Missouri	3 to 4	Elevating grader	5-7	5.7	2,000	168.0	29.02	0.015
	Horsepower							
North Carolina, Illinois	20 to 25	2-wheel, 8-foot blade	6-7	24.7	1,113	702 0	38.08	0 034
Oklahoma	35 to 40	4-wheel, 9-foot blade	3	60.3	2,351	1,172.0	31.04	0.013
Oklahoma	40	4-wheel, 10-foot blade	3	32.3	2,119	533.0	26.49	0.013
Alabama, South Carolina, Virginia, Louisiana, Missouri, Oklahoma	35 to 40	2-wheel, 10-foot blade	4-9	378.8	1,417	6,186.0	24.33	0.017
Georgia	55	2-wheel, 10-foot blade	8	102.3	1,020	1,352.0	21.65	0.021
Oklahoma	50	4-wheel, 10-foot blade	3	23.8	2,599	454.0	35.14	0.014
Texas	50	4-wheel, 12-foot blade	2	86.0	1,961	1,380.0	33.00	0.017
Region 2	40	10-foot blade	3-8	5,017.0	1,331	77,741.0	22.39	0.017
Region 4	40 to 50	10- to 12-foot blade	3-5	1,059.2	2,599	25,247.0	38.19	0.015
Region 5	30 to 40	8- to 10-foot blade	6-8	230.5	2,138	8,498.0	54 04[1]	0.025
Region 7	40 to 50	10- to 12-foot blade	3-5	1,212.0	2,352	29,320.0	33.85	0.014

Cost of outlets is not included.

[1] Higher costs are in part due to the newness of the work and to inexperienced operators.

It requires considerable experience and perseverance to develop proficiency in terrace construction. The following are a few of the more important principles to be observed in the operation of terracing equipment:

1. Unless necessary, never remove soil from areas that later will require filling.
2. Move the soil as few times as possible.
3. It is generally easier to move soil down the slope.
4. It is difficult to move loose earth over loose earth with a blade terracer.
5. Earth can be moved most efficiently if the blade is cutting some undisturbed earth at all times.
6. Move as much earth each trip as the power will permit.
7. Regulate the blade so that uniform cuts will be secured. This is particularly important on curves.
8. Do not disturb the topsoil from a wider area than is necessary.
9. It is usually desirable to secure the necessary terrace height as early during construction as possible.
10. Under varying soil conditions adjust the angle of the blade so that satisfactory scouring will be secured.

390. Terrace Cultivation and Maintenance.—All terraces should be closely watched during the first year while the loose soil is settling, and, after each rain of sufficient magnitude to cause run-off, minor adjustments and repairs will probably be necessary. During the period of settling it is advisable to seed the entire field to some kind of cover crop and not subject the fresh terraces to the hazard of open cultivation.

The amount of subsequent maintenance will be dependent upon the skill with which the terraces were designed and constructed and upon the judgment used in planning the cropping and cultivation system. Each year the field is in open-tilled row crops, one or more rounds with a plow, V-drag, small grader, or Whirlwind terracer will probably be needed after harvest to reestablish the bank height and clean out the channel. Some damage to the embankment is unavoidable with even the utmost care and is not due entirely to the furrows of row crops, as can be seen from Fig. 201. In the main, however, the amount of such maintenance will be determined by the direction in which the furrows are run during times when crops are grown.

391. Plowing Terraced Land.—All terraced land should be plowed on the contour as nearly as possible and still maintain approximate parallelism with the terraces. Plowing should never be done straight up and down hill, whether the land is terraced or not. The proper direction of plowing with respect to contours and the terraces is shown in Fig. 202. By backfurrowing always to the terrace bank the work of maintaining adequate height is minimized and the embankment base is broadened. It is desirable to shift the dead-furrow position more or less each time the field is plowed to round out the embankment cross-section and keep the interterrace slope uniform.

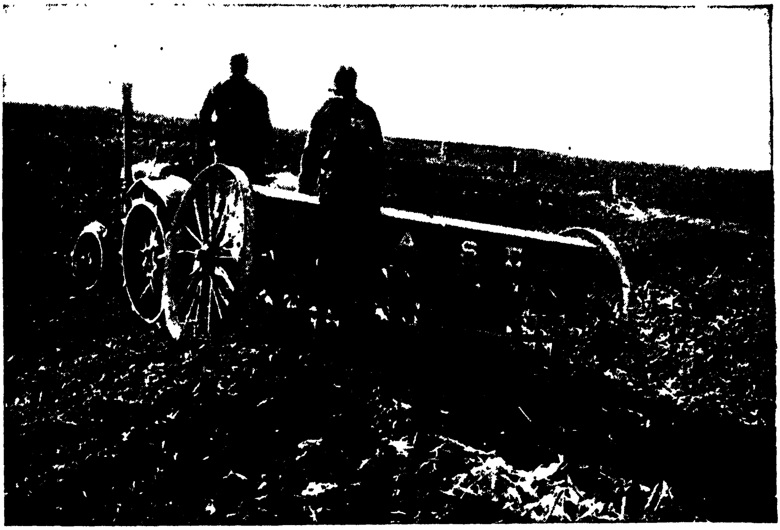


FIG. 201.—Sowing oats across terrace with a 16-foot grain drill. (*Courtesy of U. S. Bureau of Agricultural Engineering.*)

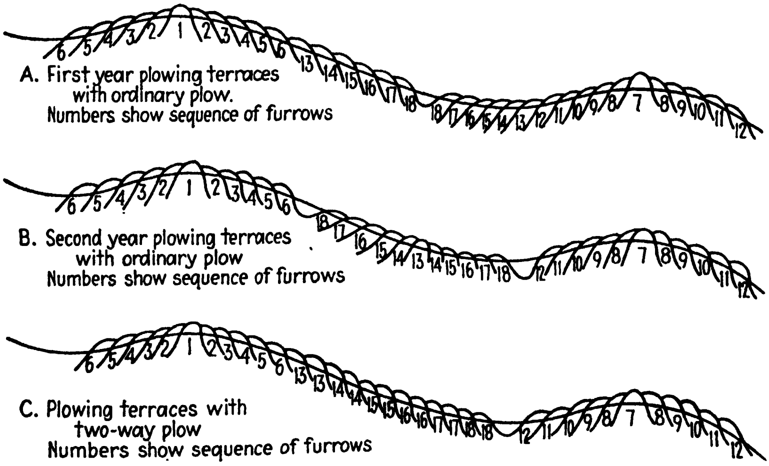

A. First year plowing terraces
with ordinary plow.
Numbers show sequence of furrows
B. Second year plowing terraces
with ordinary plow
Numbers show sequence of furrows
C. Plowing terraces with
two-way plow
Numbers show sequence of furrows

FIG. 202.—Method of plowing terraces with ordinary plow and with two-way plow.

By making use of a two-way plow the dead furrow may be located permanently in the channel and the interterrace soil always moved uphill. This more than compensates for the natural tendency to move downhill and eventually results in a smooth uniform slope from the crest of each terrace embankment to the channel next below. Another advantage of two-way plowing is greater ease in handling lands of irregular width due to lack of parallelism in the terrace lines.

The Alabama practice of plowing for easy maintenance when cleanly cultivated crops are grown is to plow out the channel at least twice during the year by measuring from the embankment center line to the lowest part of the channel and using this distance as a guide in plowing. For instance, if this distance is 7 feet, the first furrow is placed an equal distance up the slope, or 7 feet from the low point in the channel, and turned uphill. On the return trip a backfurrow is placed on the terrace bank and the plowing continued until a strip 14 feet wide has been opened. The remaining area between the terraces is then broken as a separate land.

392. Row Crops and Terraces.—It is recognized that the presence of terraces in cultivated fields introduces complications in laying out the rows that require considerable thought and study. Where the terraces are very crooked and irregular on steep slopes, row crops may become impracticable, but in the great majority of cases a satisfactory solution can be applied without causing unreasonable inconvenience.

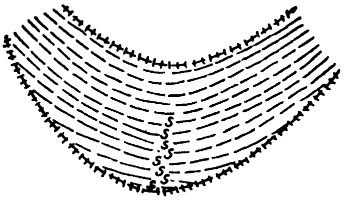


FIG. 203.—Rows parallel to upper terrace.

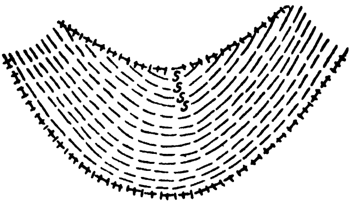


FIG. 204.—Rows parallel to lower terrace.

There are four ways of running rows on terraced land—with the upper terrace, with the lower terrace, with both terraces, and across the terrace. Where the rows are run with the upper terrace, the short rows are thrown against the lower terrace. The advantage of this method is that the short rows, by being next to the lower terrace, are easily cultivated, as the terrace is used to turn on. The rows are easy to lay off in that the first row runs parallel to the upper terrace and the rest of the rows are parallel to it (see Fig. 203).

Running the rows with the lower terrace is not very often done, as to do so causes the short rows to be next to the upper terrace and being so placed, to concentrate their water at certain points and cause a wash in the field (see Fig. 204).

Running the rows parallel to both terraces is, perhaps, one of the most common methods used, as it tends to give the rows the same fall as the terrace and prevents concentration of water at one place. The disadvantage of this is that the short rows come between the long rows in the center of the field, which makes them more difficult to cultivate. Then, too, the rows are a little more difficult to lay out (see Fig. 205).

The running of rows across the terrace was first practiced by Mangum of North Carolina. He gives the rows the same fall, or perhaps a little greater fall, in the opposite direction to which the water runs in the terrace and cultivates them right across the terrace. Hence, there are no wastelands in his field and very few short rows. This method can be used on flat slopes and where the terraces are properly constructed. Where the terraces are small, narrow and high, this system would not work at all, because they would be plowed up, and water would cut through.

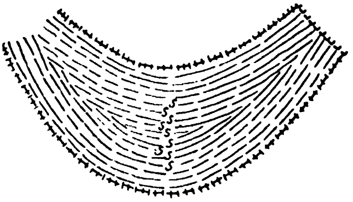


FIG. 205.—Rows parallel to both terraces.

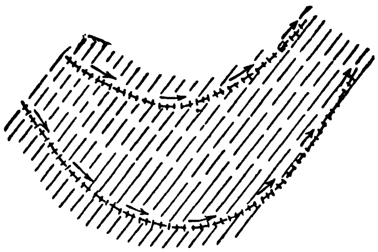


FIG. 206.—Rows running across terraces.

393. Strip Crops and Terraces.—In regard to using a combination of strip crops and terraces Hamilton says:[1]

> A combination of strip cropping and terracing that provides for close-growing crops on alternate terrace intervals and for row crops on the intervening one merely complicates the tillage and harvesting operations and does not provide any better erosion control than would be effected by terracing and by rotating the same crops in the usual method. The most effective methods of combining terracing and strip cropping are illustrated in Fig. 207.

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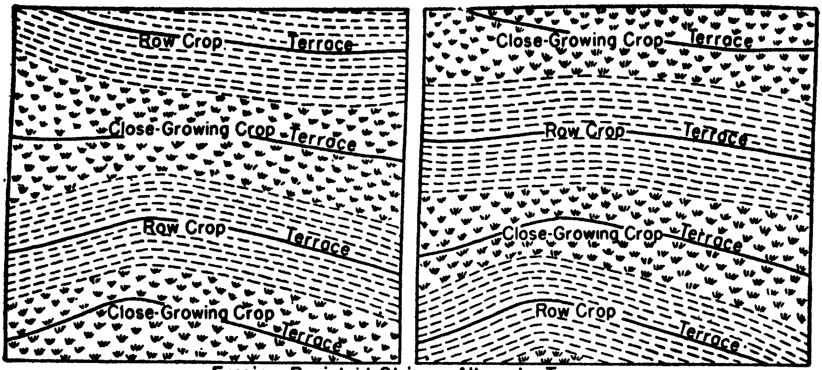
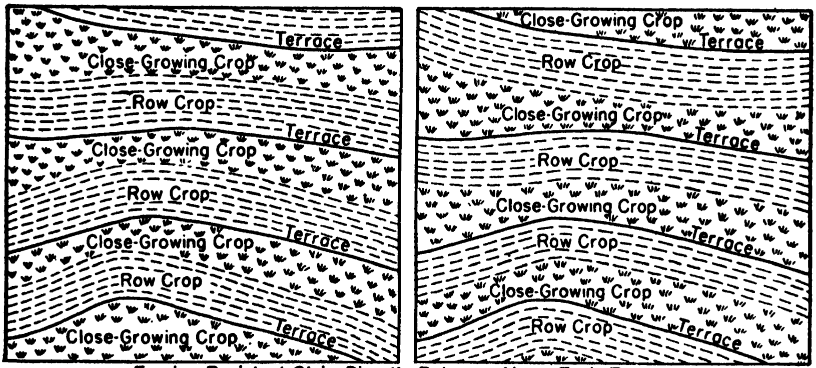
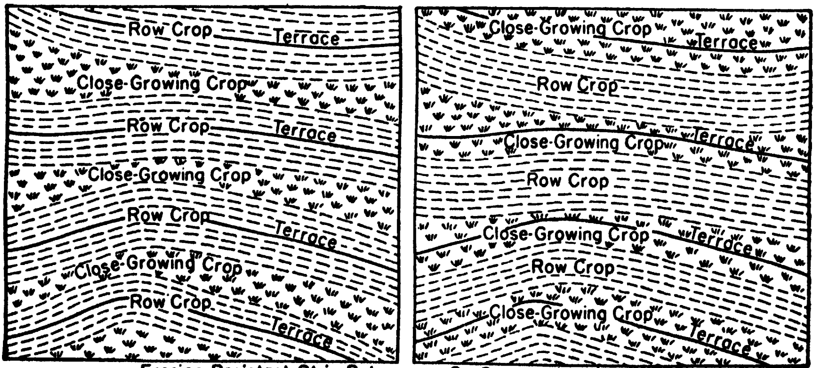
[1] *U.S.D.A. Farmers' Bull.* 1789.



Erosion-Resistant Strip on Alternate Terraces



Erosion-Resistant Strip Directly Below or Above Each Terrace



Erosion-Resistant Strip Between or On Consecutive Terraces

FIG. 207.—Three effective methods of combining terracing and strip cropping. (*U. S. D. A. Farmers' Bull.* 1789.)

394. Terrace Outlets.—Nothing is more vital to the success of a system of terraces than good, dependable outlets, and, strangely enough, nothing seems to have been more neglected. In extreme cases the expense of providing satisfactory outlets may nullify what otherwise would be a feasible undertaking. It goes without saying that, unless the run-off can be delivered to regular watercourses at the foot of slopes without harmful erosion or gullying, the terraces themselves will give only temporary protection to the main body of the field. There is also the question of legal liability for damage to consider, as laws of the humid states quite generally forbid the diversion of water from its natural direction of flow in such a way as to cause injury to adjoining property.

The selection, preparation, and maintenance of outlets in erosion-proof condition are indeed problems of prime importance; and no part of the terracing program is more subject to local variation. This is due not only to differences in environment for the legumes and grasses used in control but to variations in soil and run-off requirements and availability of natural outlets. For instance, in the transition zone between humid and arid conditions, such as the whole of North Dakota and parts of South Dakota, Nebraska, Kansas, Oklahoma, and Texas, no outlets are needed because terraces can be built level and all the rainfall forced into the soil. The other extreme is found in regions of heavy rainfall and impervious soil, too badly depleted to grow grass, where the expense of permanent structures is often prohibitive. The vast majority of cases will, of course, fall somewhere between these two extremes.

395. Location.—The importance of outlet possibilities in planning terrace layouts has already been discussed, and this idea should now be carried one step further and considered in relation to possible rearrangement of fields to conform to future crop rotations. It is not always possible on land subject to erosion to adhere to the conventional rectangular or square shapes, however desirable these may be for the most efficient operation of machinery.

A well-thought-out field arrangement from a conservation point of view is shown in Fig. 208, which also may be considered as a typical example of the work of the Soil Conservation Service in the Bethany, Mo., area. Note that the three terraced fields are approximately the same size and lend themselves readily to a three-year rotation of corn, oats, and clover. The three steeper fields, designated 4, 5, and 7, are to be left in permanent pasture, and Field No. 8 is to be planted to black locust trees to help control erosion in the gullies. The cross lines and other symbols shown in the gullies represent control structures, the design and construction of which will be considered later.

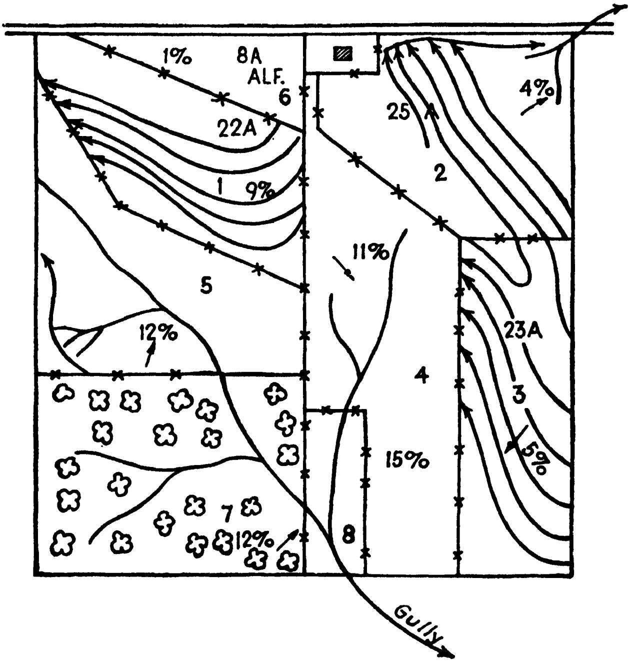


FIG. 208.—Farm map showing desirable arrangement of fields and terrace outlets on a farm of rolling topography.

Fields 1, 2, and 3 rotation
Fields 4, 5, and 7 pasture
Field 6 alfalfa, and 8 black locust
Field 1, terrace outlet into permanent pasture
Field 2, terrace outlet constructed along road; does not materially change rate of drainage through road culvert
Field 3, terrace outlet into permanent pasture

396. Natural Outlets.—The ideal outlet is a dense growth of underbrush and timber on a moderate slope with a thick mulch of leaves and débris to spread out and partially absorb the water discharged from the terrace channels. Such an outlet is represented by Fig. 209, which pictures a scene in southern Georgia.

Next to woodland of the kind illustrated, a permanent pasture of tough sod that is not overgrazed is most satisfactory.

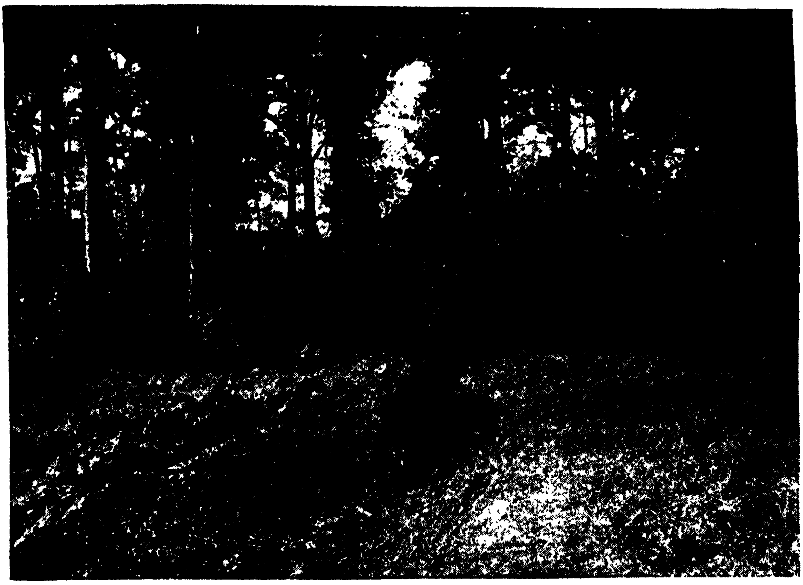


Fig. 209.—Ideal natural outlet for terraces. A thick stand of underbrush and timber on a moderate slope.

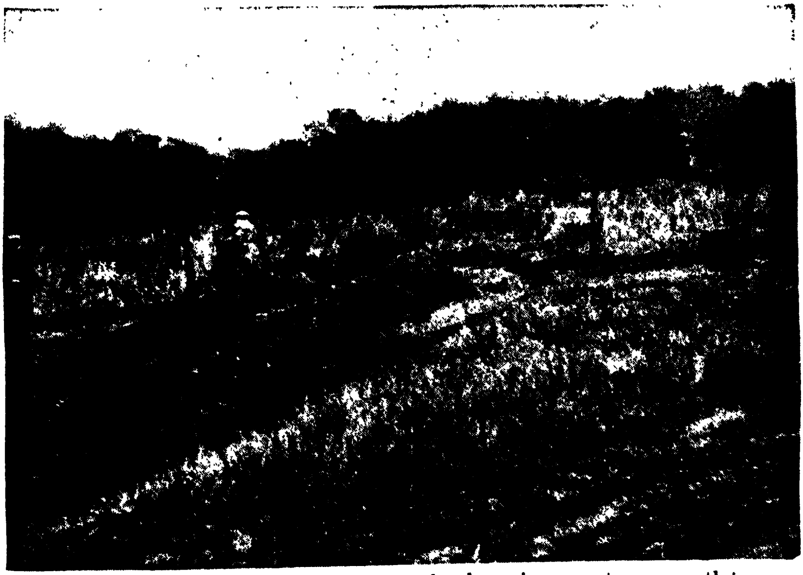


Fig. 210.—Partially grazed pasture land serving as a terrace outlet.

In both cases it is good practice to extend each alternate terrace about 15 or 20 feet into the pasture or woods and stop the others at the grass edge in order to assist in thinning out the water and preventing its concentration. Figure 210 shows a terrace extended into the sod of a good pasture outlet.

Many terrace systems, especially in the South, have been discharging for years into natural outlets with entirely satisfactory results and with no extra cost whatever. Where thin grass or trees on steep slopes have been depended upon, however, enough cases of harmful erosion and gullying are on record to justify caution in making a choice and care in watching for evidences of failure. It is a mistake to place too much dependence on a natural outlet simply because it is natural.

397. Constructed Outlets.—A majority of the more difficult terracing jobs will require one or more specially constructed ditches to serve as terrace outlets. These ditches are most commonly located along fence lines or parallel to public roads, and they are ordinarily excavated with the same equipment used to build the terraces. Sometimes a draw or watercourse is found in such a position that it can be utilized, in which case no excavation will be necessary. Almost without exception, outlet ditches are necessarily located on gradients steep enough to produce erosive velocities and hence require protection.

It is seldom advisable to empty terraces directly into road ditches, as the protection necessary both at the overfall and in the ditch itself usually throws the choice to some other alternative. Neglect of such protection in the past has been responsible for more terrace failures than any other single cause. If the road in question is part of a highly improved system, it is quite possible that highway officials will be glad to cooperate in providing for complete and safe disposition of the water. In any event, they should be consulted before using any road ditch for this purpose.

398. Channel Design.—A study of Manning's formula, which is repeated here for convenience,

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

and its companion formula,

$$Q = aV$$

shows that, for a given value of n and S, the velocity varies with the hydraulic radius. Since terrace outlets are usually located on steep slopes, it is desirable to reduce the velocity for a given discharge to as low a value as possible, and this can be done by designing the channel of such shape as to result in a minimum hydraulic radius. Remembering that the hydraulic radius is the quotient of the cross-sectional channel area divided by the wetted perimeter, it is seen that the larger the wetted perimeter, for a given area, the smaller will be the quotient. This is another way of saying that a given volume of water flowing down a given slope will be carried at a velocity that varies from a minimum for a wide shallow channel to a maximum for a narrow deep one. In wide shallow channels the bottom width may be assumed as the wetted perimeter with negligible error.

399. Vegetative Control.—Where permanent vegetation alone is relied upon for control, the maximum velocity to be attained, on the average not oftener than once in 10 years, should be set at 8 feet per second. This is for best sod cover on ground containing not less than 50 per cent topsoil. For sod of poorer quality the 10-year maximum velocity should be reduced to 6 or even 4 feet per second, depending upon the amount of topsoil present and the vigor of the stand. Assuming a maximum velocity of 5 feet per second and a roughness coefficient n of 0.04, channels of the widths shown on the curves of Fig. 211, flowing at a depth of one-twelfth the width, will have capacity to carry the amount of run-off shown as ordinates on the various slopes shown as abscissæ. Twelve per cent is considered the maximum slope where vegetation alone can be depended upon for safe control.

The minimum flow depth for any considerable period of time should be not less than 3 inches, and the outlet gradient should be 6 inches lower than the terrace gradient at the point of intersection. If this 6-inch drop is distributed over at least 10 feet of the terrace by hand work there is little danger of erosion. Where this drop is more than 1 foot, an outlet structure will probably be necessary.

To provide a "freeboard" of 4 to 6 inches at the sides of the outlet channel above the computed depth of flow without deepening the gradient undesirably, it will be necessary in most cases to throw up banks of earth or levees at the sides in addition to the work of excavation. Since the discharge increases below the mouth of each terrace, the outlet width will need to be increased correspondingly when the critical discharge for the former width is exceeded. These width changes should be made gradually to avoid abrupt variations in cross-section.

Many of the methods described in the following chapter for the control of gullies apply equally well to terrace outlets; particularly the structures used to transmit water from one level to another. Outlets of tile or second-grade sewer pipe have also been used in a manner similar to that illustrated in Fig. 198 for draining pockets above terraces.

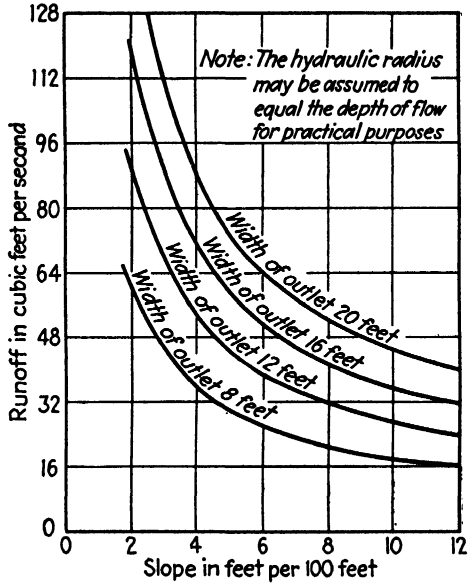


FIG. 211.—Limiting run-off for vegetatively controlled outlets for different slopes.

CHAPTER XXIII

CONTROL OF GULLIES

Theoretically, if a farm contains land in varying stages of erosion, it is logical to protect the best land from further loss first, but usually it is more practical to begin with the gullies if they are not too far gone. Numerous attempts have been made to group gullies into classes and prescribe treatment accordingly, but too many variables must be considered to enable this to work out well in practice. The best treatment of a given gully depends upon the gully location and dimensions; side and longitudinal channel slopes; size, shape, prevailing slope, cover, and drainage conditions of watershed; type of soil; and upon whether the gully is to be filled and restored to crop use, partially filled and used as a drainage channel, or merely protected against further enlargement.

In the final analysis, it is the volume and rate of run-off that is most influential in determining possible methods of control. Run-off, in turn, is a measure of the net effect of various combinations of the above-named factors.

400. Treatment of Small Gullies.—For checking small gullies, structures of the type to be described later are seldom necessary. Oftentimes finger gullies appear in a field that is later terraced. Diverting the water, by terracing, and cultivation eliminate the trouble.

If the gullies approach the upper limit in size for the "small" classification, a series of checks made of bags full of sod, or some one of several patented devices, may be used. These latter include sections of heavy wire bent into prongs and crimped into light channel beams, and corrugated metal checks made complete in one unit. The prong check sections are 3 feet long and 1½ feet high, are light enough to be easily handled, and can be moved from one part of the field to another as the fills become made. The corrugated metal check is double reverse-curved in plan and is particularly well adapted to side ditches along highways (see Fig. 212).

Should the cause of the gully be accidental or adventitious, such as having started from a wagon rut or cattle path, it may safely be filled with straw or brush and the sides plowed in. This is a practice, however, that seldom works in other types of gullies, unless anchorage for the brush is provided or the water diverted. Successive stages in the restoration of a gully treated in this way are illustrated in Figs. 213 and 214. To prevent the formation of gullies in cultivated fields, it is commonly recommended that longitudinal sod strips be left undisturbed along the thalweg or flow line of swales and depressions. If the sod strips are not too narrow, this practice is usually effective but only at the price of considerable inconvenience in plowing and cultivating, and it sometimes involves the sacrifice of appreciable

Fig. 212.—Series of corrugated metal checks in side ditch of freshly graded road. Ditch gradient, 20 feet per 100 feet. Picture taken just after a 4-inch cloudburst. (*Courtesy of Iowa Culvert and Pipe Co.*)

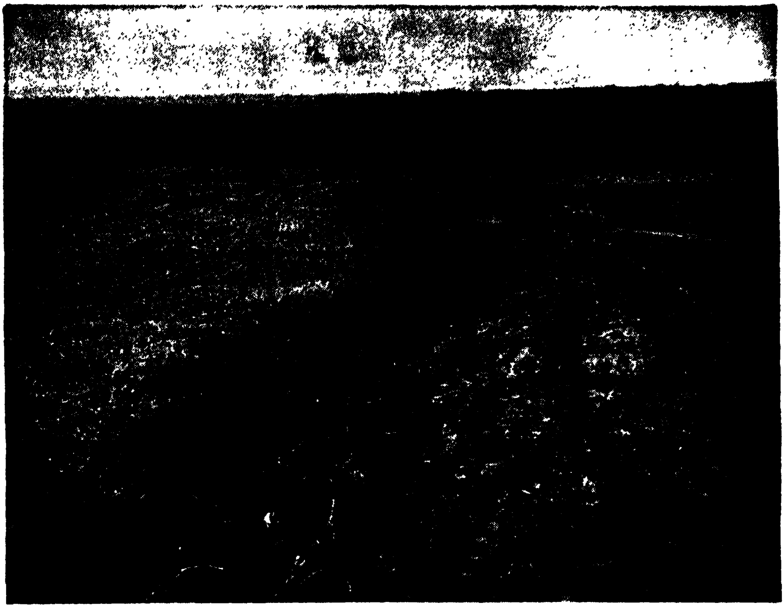


FIG. 213.—Original condition of small gully in a field to be terraced.

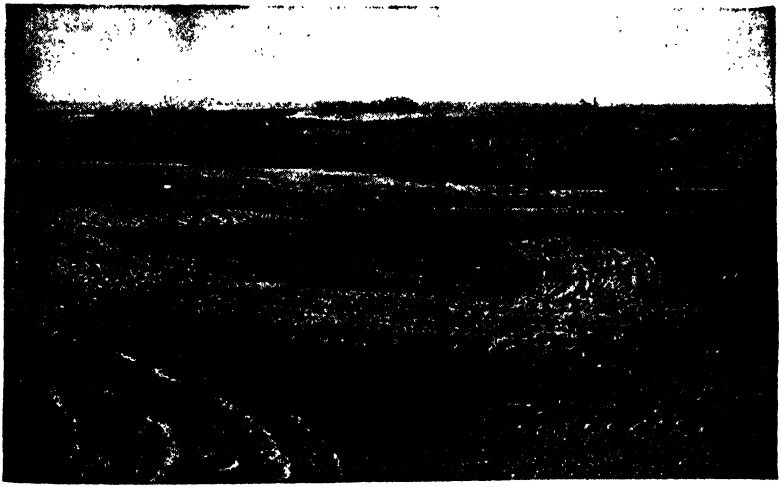


FIG. 214.—Gully shown in Fig. 213 after being filled with brush, plowed in, and terraced. Field is ready for crops.

areas of land from crop production. Uncontrolled weeds also become a menace.

Small gullies are sometimes reclaimed by laying drain tile throughout their length and plowing in the sides. This is a very effective method but is relatively expensive.

401. Check Dams for Gully Planting.—The ultimate purpose of building most check dams is to make possible the restoration of natural control through the growth of vegetation. In localities where sufficient topsoil remains and climatic and other conditions are favorable, vegetation will frequently reestablish itself without special effort on the part of man. Normally, however, devastation has advanced so far in gullied areas that unassisted natural revegetation will at best be sporadic and will require an inordinate length of time to become effective.

Four general types of vegetation are available: trees, shrubs, vines, and grass.

It is essential that correct structures be made for successful planting. They usually should be of an inexpensive temporary type, but capable of holding the soil until the trees or other vegetation are established (a period of about 5 years). Their heights, generally from around 8 to 30 inches, should vary with the depth of the gully and the amount of soil to be caught for the plants. The ends of the dams should not be constructed so as to interfere with the necessary sloping of the banks for planting. Spaces between dams should contain sufficient earth for satisfactory settings.

If heavy drainage comes periodically through the gully to be planted, one or more permanent low structures may be necessary in order to stabilize the bottom, since such run-off from areas above would otherwise continue to cut the channels deeper and cause the banks to fall in. The plants would thus have no chance to establish themselves. If the gully bottom is stabilized, trees will grow on it, even though there may be an occasional flow of water. In wind-blown and other loose soils, the cutting action of water is particularly noticeable, and gully bottoms of over 1 per cent gradient in these soils are rarely considered stabilized for tree planting.

Sometimes diversion ditches and dikes or terraces are necessary to conduct water away from the sides and heads of gullies preparatory to successful planting.

402. Sloping Gully Banks.—Working off the gully banks is desirable to secure cultivated ground in which to set plants, and many times is necessary in order to flatten the side slopes sufficiently to permit satisfactory transplanting. A declivity of 1 to 1 (45°) for the side slopes is the usual rule but, under special conditions, trees have been planted successfully on somewhat steeper side slopes.

No set time can be fixed for doing this work, but it should be performed early enough in the fall and spring to permit sowing the banks to such grasses as will produce a satisfactory covering to protect against surface wash prior to setting trees. Often it can and should be done at the time that the dams are built, as an initial deposit of earth will be provided and thus fulfill one of the objectives sought in plowing off the banks. Some of the grasses that can be used for this purpose are Bermuda grass, orchard grass, bluegrass, redtop, sweet clover, and lespedeza. Every locality has certain grasses best suited to it. Bermuda is probably one of the best grasses for Southern conditions, and it provides excellent pasture for stock. Wild honeysuckle grows luxuriantly in the South on almost barren soils. A more rapid growth can be obtained in gullies by applying elements of fertility in which the soil is deficient. Manure will supply the required elements in most soils. Sorghum is very effective in controlling erosion in gullies.

403. Principles Governing the Use of Check Dams.—The control of gullies by mechanical means is essentially a problem in applied hydraulics. Erosive velocities are reduced by constructing a series of checks which, in time, transform the longitudinal gradient of the gully from a uniform, steep slope to a succession of "steps" with low risers and long flat treads. These checks are usually of temporary character and serve to hold the fill and prevent washing while vegetation for permanent control is becoming established. If the intention is to fill the gully completely, additional checks are later built midway between the original structures, and this process is repeated as many times as may be necessary.

When the fill is complete, future drainage must be diverted by terraces, or else the fill must be left under a cover of undisturbed sod to prevent a recurrence of scour. Substantial checks of creosoted planks, masonry, or concrete are built where it is necessary to rely upon these alone for permanent or semipermanent control. Earth dams with drop-inlet culverts are generally resorted to when both the gully to be reclaimed and its watershed are large.

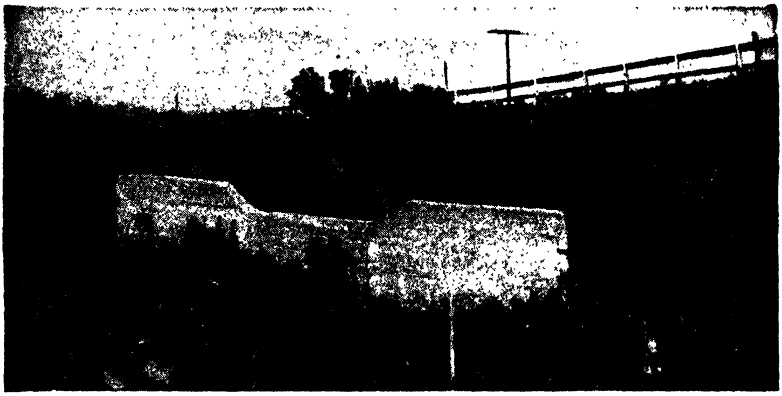


Fig. 215.—A check dam of permanent construction washed out around the ends due to insufficient notch capacity.

404. Notch Capacity Required.—A very common cause of failure of checks, both temporary and permanent, to perform the function intended is insufficient notch capacity. Unless the

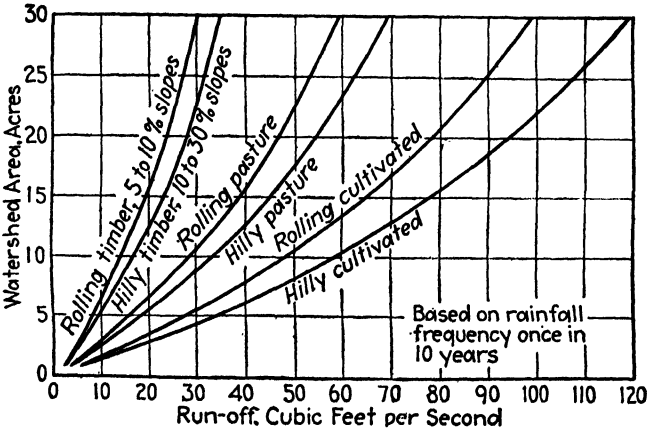


Fig. 216.—Suggested curves showing run-off to be discharged through the notches of check dams.

notch is large enough to discharge water from intense rains without flooding the banks, the check is almost sure to be washed out around the ends and become ineffective. Figure 215 illustrates such a condition. It is therefore of first importance that the notch area conform to the requirements of Table 37.

To use the table it is first necessary to determine the run-off to be allowed for in cubic feet per second. When the watershed characteristics for the area under consideration are known this can be taken from the curves in Fig. 216. These curves are based on average conditions obtaining in the belt designated as Group 3 on the map shown in Fig. 217. Results secured from their use should be modified to conform to local conditions. As a rule, run-offs in Group 2 and Group 1 of Fig. 217 will be larger because of the greater number of intense storms occurring in those localities.

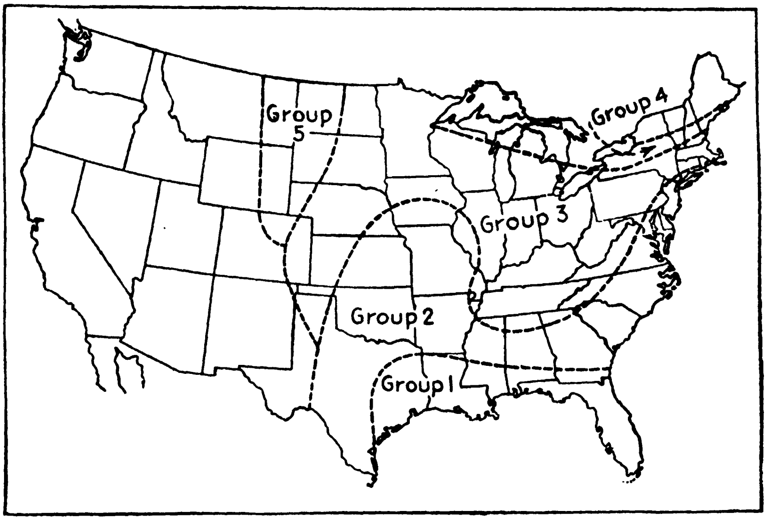


FIG. 217.—Boundaries of areas of similar rainfall intensities for short periods. (*Meyers' "Hydrology."*)

Example.—To illustrate, suppose the watershed lying above a given check dam consists of 30 acres of land with slopes between 5 and 10 per cent, which would be classed as "rolling." Suppose further that about one-third of the watershed is cultivated, one-third pasture, and one-third timber. On the scale at the left of Fig. 216 follow the horizontal line opposite "30" (which happens to be at the top) to the right until it intersects the curve marked "rolling timber." Then follow down the vertical line to the point of intersection with the horizontal axis where the run-off for this condition is found to be 30.0 cubic feet per second. One-third of 30.0 is 10.0 cubic feet per second. Go back to the 30-acre line and continue until the "rolling pasture" curve is intersected. Following down the vertical line the run-off is seen to be 59.0 cubic feet per second, one-third of which is 19.7 cubic feet

TABLE 37.—DISCHARGE IN CUBIC FEET PER SECOND FOR WEIR NOTCHES IN EROSION CHECK DAMS

Computed by formula

$$Q = 3.39LH^{3/2}*$$

where Q = discharge in cubic feet per second.
L = length of weir notch in feet.
H = depth of weir notch in feet.

NOTE.—The Wisconsin model tests indicate that for weir-notch dams of special design and operating under a maximum head of 1.5 feet under ideal conditions, the coefficient in this formula may be increased to 3.60.

Depth of weir notch, feet	Length of weir notch, feet								Depth of weir notch, feet
	1	2	3	4	5	6	7	8	
0.5	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	0.5
1.0	3.4	6.8	10.2	13.6	17.0	20.3	23.7	27.1	1.0
1.5	6.2	12.5	18.7	24.9	31.1	37.4	43.6	49.8	1.5
2.0	9.6	19.2	28.8	38.3	47.9	57.5	67.1	76.7	2.0
2.5	13.4	26.8	40.2	53.6	67.0	80.4	93.8	107.2	2.5
3.0	17.6	35.2	52.8	70.5	88.1	105.7	123.3	140.9	3.0
3.5	22.2	44.4	66.6	88.8	111.0	133.2	155.4	177.6	3.5
4.0	27.1	54.2	81.4	107.5	135.6	162.7	189.8	217.0	4.0
4.5	32.4	64.7	97.1	129.4	161.1	194.2	226.5	258.9	4.5
5.0	37.9	75.8	113.7	151.6	189.5	227.4	265.3	303.2	5.0
	9	10	11	12	13	14	15	16	
0.5	10.8	12.0	13.2	14.4	15.6	16.8	18.0	19.2	0.5
1.0	30.5	33.9	37.3	40.7	44.1	47.5	50.9	54.3	1.0
1.5	56.0	62.3	68.5	74.7	81.0	87.2	93.4	99.6	1.5
2.0	86.3	95.9	105.5	115.0	124.6	134.2	143.8	153.4	2.0
2.5	120.6	134.0	147.4	160.8	174.2	187.6	201.0	214.4	2.5
3.0	158.5	176.1	193.8	211.4	229.0	246.6	264.2	281.8	3.0
3.5	199.8	222.0	224.2	266.4	288.6	310.8	333.0	355.2	3.5
4.0	244.1	271.2	298.3	325.4	352.6	379.7	406.8	433.9	4.0
4.5	291.2	323.6	356.0	388.3	420.7	453.1	485.4	517.8	4.5
5.0	341.1	379.0	416.9	454.8	492.7	530.6	538.5	606.4	5.0

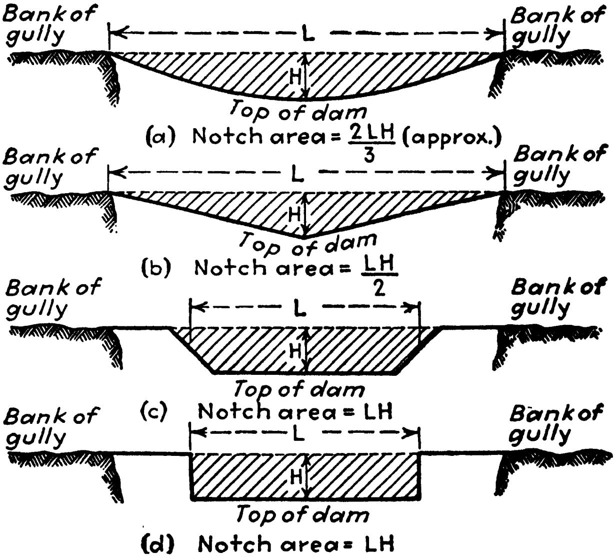
* King's *Handbook of Hydraulics*.

per second. Repeat this process once again for the "rolling cultivated" curve where 99.0 cubic feet per second is found to be the run-off, and one-third of 99.0 is 33.0 cubic feet per second. The total run-off to be provided for then is

$$10.0 + 19.7 + 33.0 = 62.7 \text{ cubic feet per second}$$

> It is important to note that the proper figure is arrived at in this manner and *not* by adding the run-off from 10 acres of timber, pasture, and cultivated land. The reason for this is that the smaller the acreage, other factors remaining constant, the less time is required for water to concentrate at a common outlet, and the smaller the time of concentration the higher the rate of rainfall, and hence run-off, that must be provided for.
>
> For the assumed problem, then, the required discharge capacity is 62.7 cubic feet per second. Suppose the gully is of such dimensions that a length of 7 feet is practicable for the notch. Entering Table 37 on the top line there is found under the numeral "7" and horizontally opposite the numeral "2.0" in the left-hand column, 67.1 cubic feet per second. This means that a notch 7 feet long and 2 feet deep would have a capacity slightly in excess of the required amount and is, therefore, the size that should be used. If only 5 feet of length had been available, the corresponding depth would need to be 2.5 feet.

This is easy to apply to checks of a type where rectangular notches are a part of the design. For other types, such as brush and wire checks, the center portion must be made low enough to allow, underneath a straight line joining the ends of the structure from bank to bank, the approximate notch area required.



(a) Notch area = $\frac{2LH}{3}$ (approx.)

(b) Notch area = $\frac{LH}{2}$

(c) Notch area = LH

(d) Notch area = LH

FIG. 218.—Graphical representation of effective notch areas of check dams.

This is made clear by reference to Fig. 218, which is a graphical representation of the effective notch area of all common types of check dams. A notch area of 14 square feet is required in all cases when L equals 7 feet.[1] Thus, if the top of the dam has the shape of Case a, H in the figures would need to be 3 feet to give the necessary area, and not 2 feet as before. Similarly, H in Case b must be 4 feet, but in Cases c and d it remains 2 feet, provided L is measured as indicated.

405. Height of Check Dams.—Unless special precautions are taken the height of temporary check dams, from center of notch to bottom of gully, should not exceed 2.5 feet, and should preferably be less. For greater heights, the static pressure increases, tending to force leaks underneath the structure; and overfall scour is hard to control.

406. Spacing of Check Dams.—For purposes of explanation it might be said that checks should be spaced so that the crest elevation of one will be the same as the bottom elevation of the adjacent check upstream. In other words, assuming the check to be watertight, a pool of water would be formed extending to the apron of the next dam above. In practice, however, this ideal is not often attained because too many structures would be required. Besides, even the most erosive soils will remain stable on some gradient steeper than dead level. For the types of soil usually encountered in gullied areas, the following grades are recommended:

For coarse sand with a considerable amount of small gravel—about 2 per cent.

For fine sand and silt loam—about 1 per cent.

For lighter silts and clays—about 0.5 per cent.

These figures do not conform to those usually found in published handbooks for stabilized gradients in the various soils. This difference may be accounted for in two ways: first, the handbooks usually assume the soil to be covered with vegetation, whereas in gully control the soil must be held stable while vegetation is growing; and second, if the soil is dense and tough enough to remain stable on steep grades, no gullies are likely to occur.

So far as spacing and height are concerned, the wire checks illustrated in Fig. 219 represent good practice, but the notch capacities appear inadequate. The gully banks in this photograph have been sloped and prepared for seeding.

---

[1] This statement is not strictly correct, since weir discharges are not directly proportional to the length times the average depth. It is sufficiently accurate, however, for the purpose intended.

407. Other Design Factors.—In addition to the proper spacing and height and the allowance of ample notch capacity to take care of the run-off, check dams should be built far enough into the banks to be safe against water seeping around the ends and washing away the sides of the gully. This means that the dam must extend 1.5 to 2 feet into the *stabilized* side slopes, which are much flatter than those usually found in actively eroding gullies where the side slopes have not yet attained a permanent angle of repose.

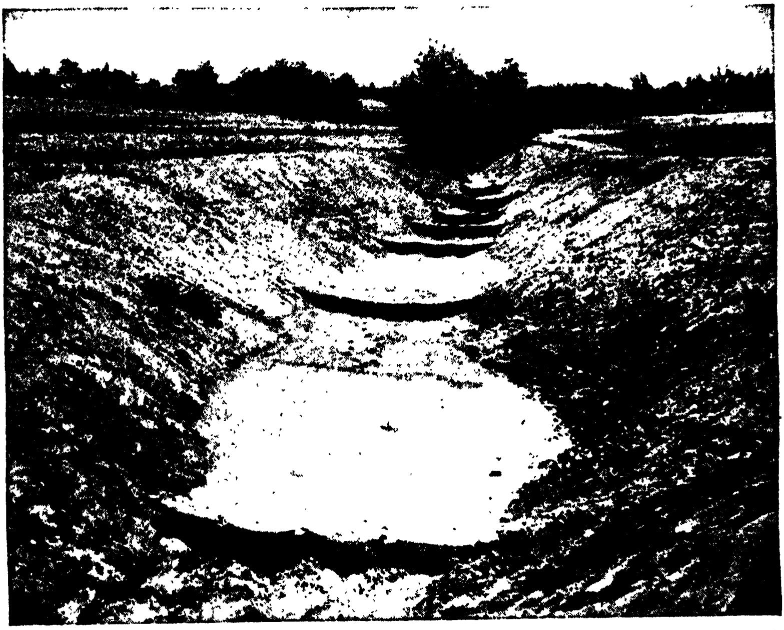


FIG. 219.—Series of wire checks illustrating usual spacing and height. Notch capacities, however, appear inadequate. The gully banks in this picture have been sloped and prepared for seeding.

Also, the checks should be trenched into the gully bottom a sufficient depth to resist undermining by static pressure, and the anchorage should be such as to withstand this pressure plus an allowance for impact of moving water and possibly ice. Loose brush and other débris thrown into a gully are generally ineffective, largely because of a tendency to float.

As an integral part of most check dams an apron or platform must be provided to catch the water falling over the top and conduct it away without scour. To accomplish this purpose the apron must be ample in both length and width. The need for this apron is less urgent and may become negligible where conditions permit a series of checks to be built so that the fill accumulated behind any one extends to the bottom of the next one above. In this case only the last or lowest check in the series requires such protection. This dam should preferably be built of permanent materials.

408. Overfall Protection.—The first point to receive attention in most gullies of appreciable size is at the upper end, where an abrupt drop or overhanging bank is generally found. When water falls over this head bank, it strikes the bottom and scours in all directions much as a waterspout or geyser would do if inverted. That part of the scour in the direction opposite to flow soon causes the bank to be undermined more and more until a section caves off and the process starts anew. Once started, gullies can advance into good land by this process a distance of 50 feet or more in one season, frequently where land slopes are flat enough to be otherwise stable.

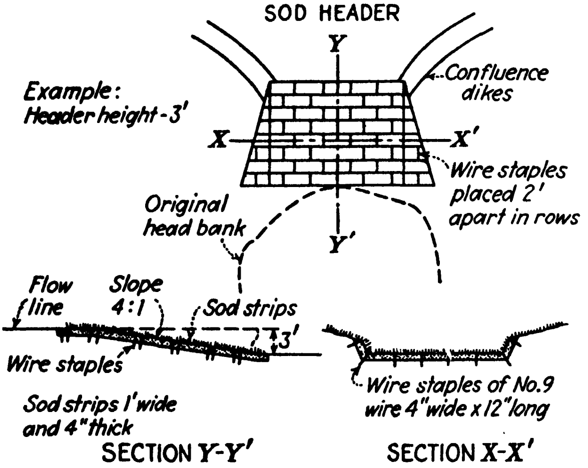


FIG. 220.—Sod header for gully overfall protection.

Unless the overfall lip is to be "submerged" by an earth dam or other permanent structure, it is generally advisable to cut back the head bank to a slope of about 4 horizontal to 1 vertical and line with sod (see Fig. 220), pave with bituminous material or concrete, install a flume of creosoted wood or galvanized metal, or build a watertight structure similar to that illustrated in Fig. 221.

409. Diversion Ditches.—The head banks of gullies in fields on which terraces are built lose their power to wreak further damage

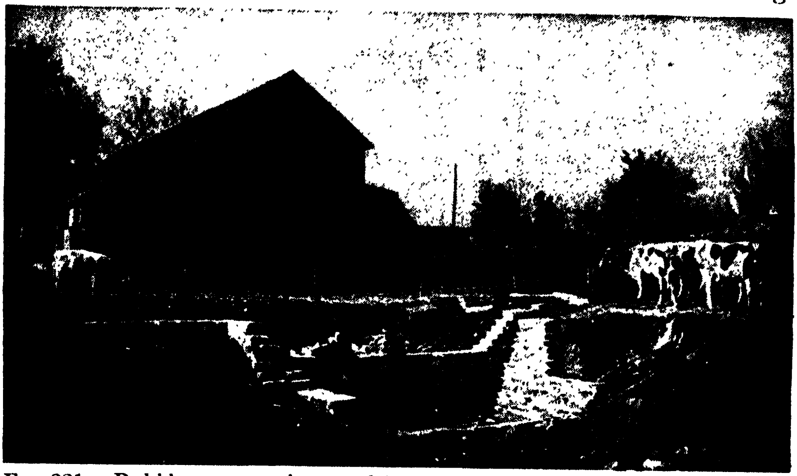


FIG. 221.—Rubble masonry dam used for head overfall protection in Minnesota.

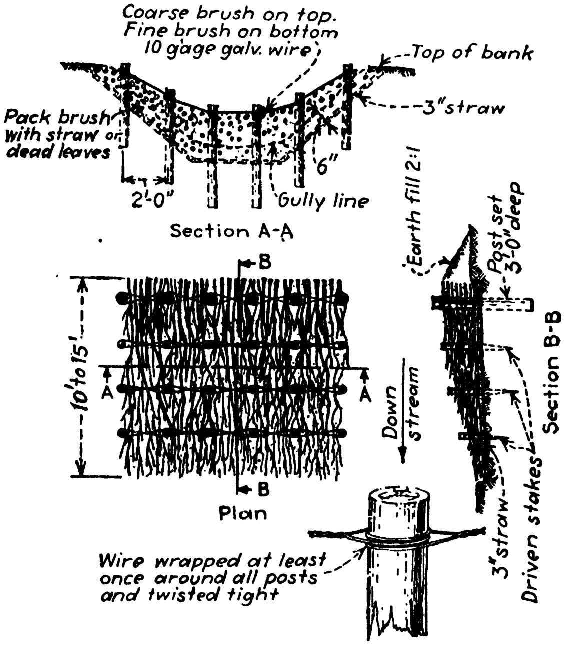


FIG. 222.—Design for single-post row, longitudinal brush type of brush dam.

because the run-off is permanently diverted to other outlets. This is the most satisfactory way of all to control head erosion, since the gully may simply be filled in and forgotten.

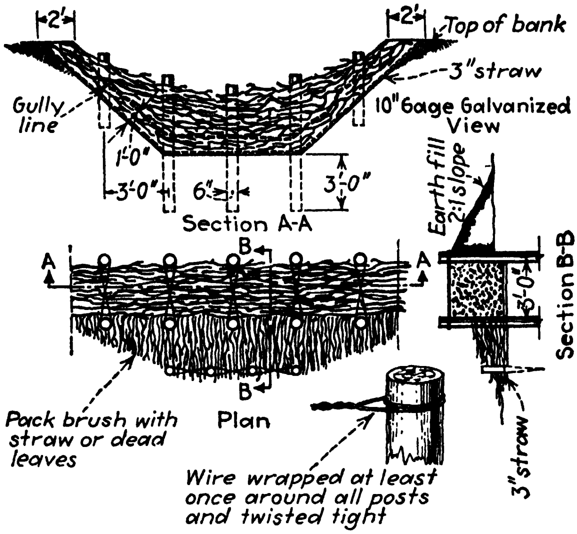


FIG. 223.—Design for double-post row, crosswise brush type of brush dam.

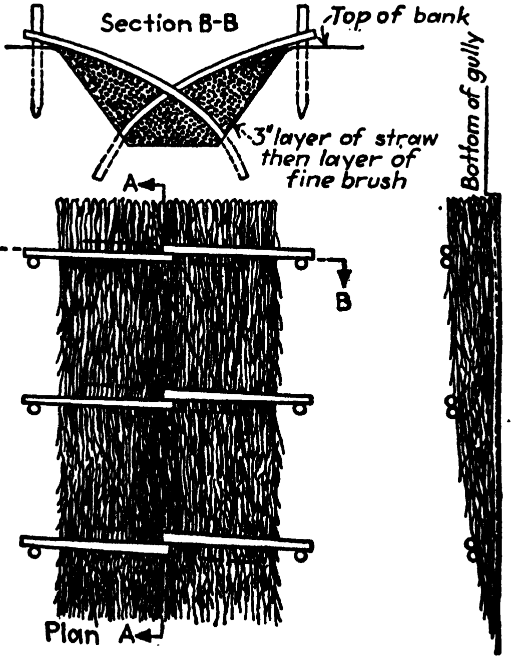
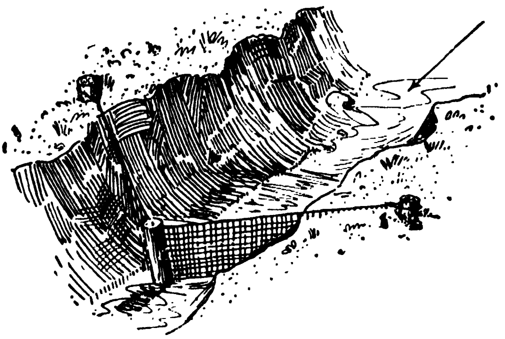


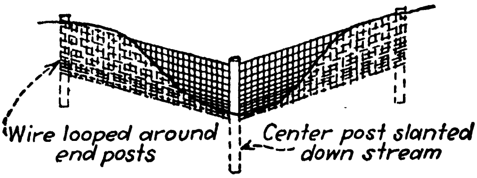
FIG. 224.—Design for pole-type brush dam.

If the circumstances are such that terraces are impracticable or are not otherwise needed, a diversion ditch above the heads of a series of gullies is frequently used to concentrate the flow in a single channel where it may more easily be dealt with.

410. Brush Dams.—Although brush dams are the least permanent of all types, are tedious to build, and are very difficult to render and keep even partially watertight, they are nevertheless recommended because of the nominal cash outlay required and because they can be made to function by giving almost constant attention to maintenance. It is believed that many farmers will prefer to build their dams of materials locally available and inspect them after every rain rather than spend money for materials of other types which are more permanent and do not require such continuous care.



Perspective



Section Looking Up Gully

FIG. 225.—V-type woven-wire check suitable for V-shaped gullies with small watersheds. Center post should not extend more than 18 inches above gully floor. Wire should be trenched into floor.

Three common types of brush dams are shown in the detailed drawings of Figs. 222, 223 and 224.

411. Woven-wire Dams.—The V-type check, shown in Fig. 225 is adapted only to gullies of V-shape or those with very narrow bottoms and small watersheds. The main construction features are the deep-set center post leaning downstream and bank trenches deep enough to bury all the wire. Special precautions should be taken to leave the top of the center post low enough to allow the waterway area required by Table 37 between it and a level line joining the banks. Eighteen inches should be the maximum center height for this type of dam, which means that some of the woven wire will have to be trenched into the gully bottom.

Other types of wire dams are shown in Figs. 226 and 227.

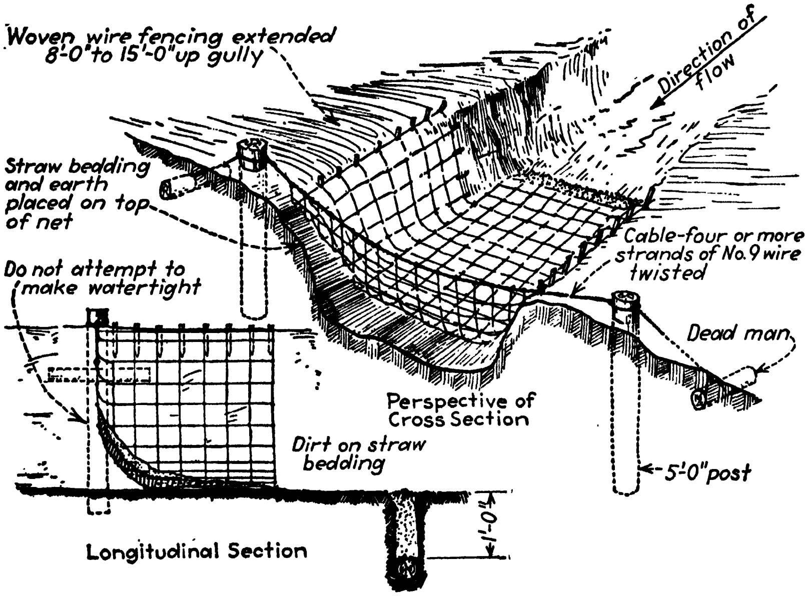

Woven wire fencing extended 8'-0" to 15'-0" up gully
Direction of flow
Straw bedding and earth placed on top of net
Cable-four or more strands of No. 9 wire twisted
Do not attempt to make watertight
Dead man
Perspective of Cross Section
Dirt on straw bedding
5'-0" post
1'-0"
Longitudinal Section

FIG. 226.—Suspended-net type of woven-wire dam.

412. Loose-rock Dams.—Where stones or rocks of appreciable size and satisfactory quality are available, they may be used as barriers in medium-sized gullies if the drainage area is not too large—say 5 to 10 acres. The stones must be carefully fitted together to make as dense a mass as possible and the structure trenched into the gully sides and bottom.

If the watershed is too large or the rocks too small, or if there is any other reason to doubt the holding power of the structure, the rocks should be set in cement mortar or enveloped in a cage of woven wire of the shape shown in Fig. 228. Vertical tie wires to increase stability should extend through the structure at intervals of at least 2 feet, crosswise of the gully and at the points of inflection. If only very small rocks are available, the tie wires should be spaced 1 foot apart in both directions.

413. Log Dams.—Where timber is plentiful or where a large number of logs 4 inches or more in diameter have accumulated

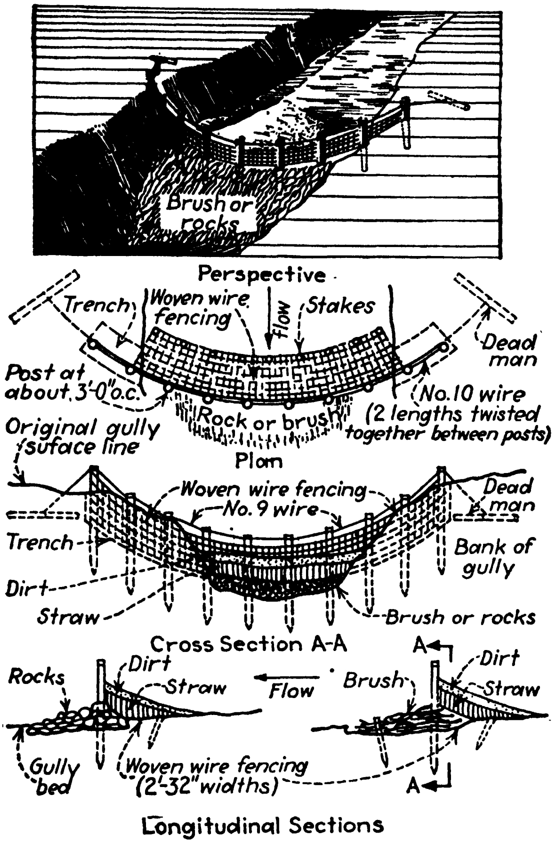
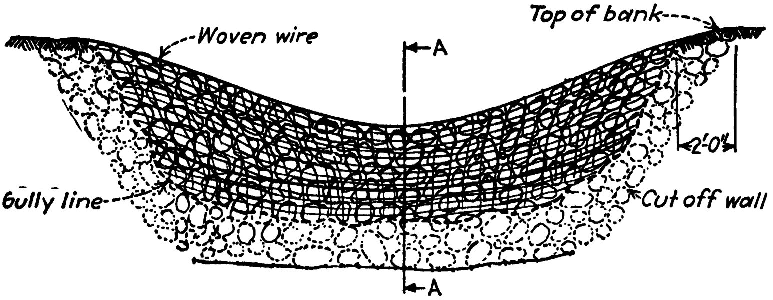


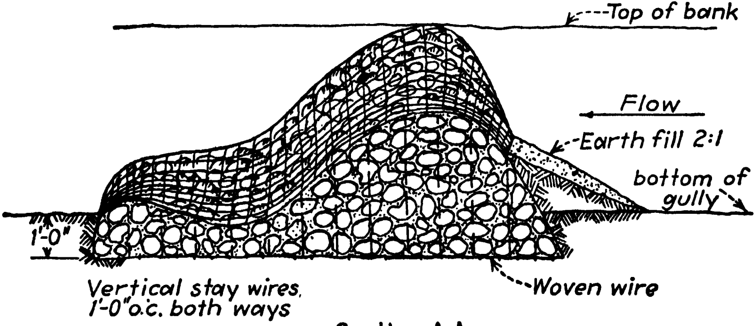
FIG. 227.—Fixed-basket type of woven-wire dam.

as remnants in the construction of brush dams, or where, as in parks, the aesthetic value of rustic structures is important, log dams fit in very nicely. On the other hand, they entail a wasteful use of both materials and labor and are suited only to the special conditions mentioned.

414. Permanent or Soil-saving Dams.—The probable life of any structure is roughly proportional to its cost, and permanent dams are no exception to the general rule. The advantages of long life and self-sufficiency, however, frequently outweigh the disadvantage of costliness in many choice comparisons; but, because of the expense, economic studies of the value of the soil saved and that of the surrounding land become increasingly important. A soil-saving dam, as the name implies, is expected to catch and hold considerable quantities of soil within its zone of influence and to prevent future losses without dependence on vegetation to aid. The presence of vegetation behind a permanent dam, therefore, represents double protection, and, as such, is to be desired.



View Looking Up Gully

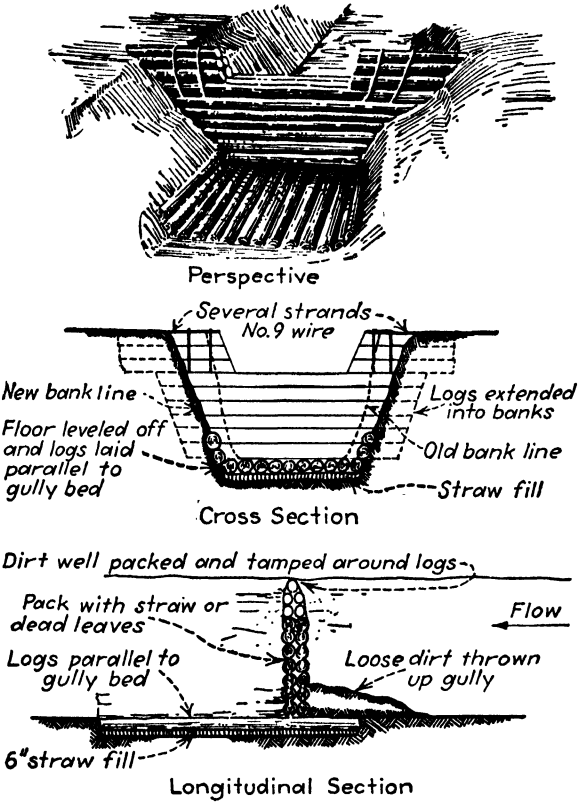


Section A-A

FIG. 228.—Loose-rock dam held in place by an envelope of woven wire.

While soil-saving dams may be, and frequently are, used as substitutes for temporary check dams in small- and medium-size gullies, their principal use is found in medium and large gullies draining watersheds of considerable size. Very often, a single dam at the lower end of a large gully system will flatten the gradient sufficiently to stop further cutting far above and beyond its anticipated zone of influence and thus enable vines, shrubs, and trees to get a start and develop protective cover throughout the length of the gully and its branches. In many cases vegetation would not have a chance to develop without the aid of the dam and, in fact, numerous instances could be cited of old established trees having the soil torn away from their roots by the force of water that was not checked mechanically.

Inasmuch as permanent dams frequently serve watersheds much larger than 30 acres, an extension of the run-off curves in



Perspective

Cross Section

Longitudinal Section

Several strands No. 9 wire
New bank line
Floor leveled off and logs laid parallel to gully bed
Logs extended into banks
Old bank line
Straw fill
Dirt well packed and tamped around logs
Pack with straw or dead leaves
Flow
Logs parallel to gully bed
Loose dirt thrown up gully
6" straw fill

FIG. 229.—Design for log dam in medium or small gullies with stable bank slopes of 1 to 1 or steeper; watershed area not to exceed 30 acres.

Fig. 216 is necessary. These curves are shown in Fig. 230, and they are used in the same manner as that previously explained. It will be noted that Figs. 216 and 230 are based on a rainfall frequency of once in 10 years. This means that the discharge capacity of structures designed from these curves is expected to be exceeded, on the average, not oftener than once in 10 years. It is assumed that the damage resulting from water in excess of the anticipated amount can be repaired once in 10 years for less than the cost of providing additional capacity. For dams with vertical drops of 15 feet or more, which usually serve very large watersheds, the probability of recurrence should be increased to longer periods, as will be shown.

Like Fig. 216, the curves of Fig. 230 are based on rainfall intensities prevailing in Group 3 of the map shown in Fig. 217.

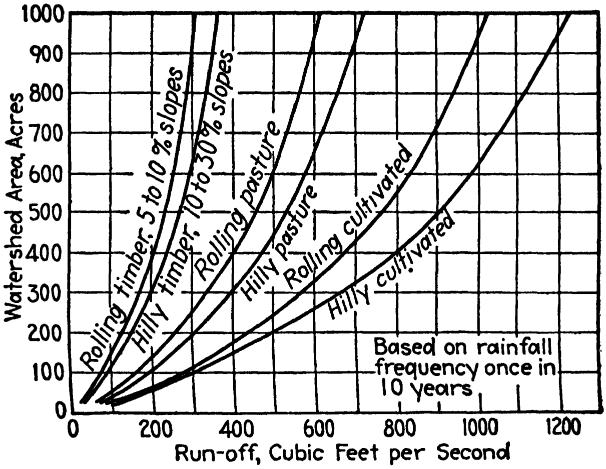


FIG. 230.—Suggested curves showing run-off to be discharged over spillways or through culverts of permanent dams with vertical drops of 15 feet or less.

415. Rubble-masonry Dams.—In areas where stone or rock of good quality abounds the rubble-masonry dam shown in Fig. 231 is ideal for drops up to 10 feet. It is neat, durable, inexpensive, and effective and can be built with unskilled labor. The plans are simple and easy to follow and, as a rule, the only cash outlay is for Portland cement. Cement mortar should invariably be used in preference to lime mortar, as it has greater binding power and is more resistant to water and frost action. The stone or rock will probably need to be broken and shaped by hand to a reasonably uniform size.

Spillway crests in permanent dams are usually broader (thicker) than the notches of check dams, and this requires the use of a smaller coefficient in capacity formulæ to allow for increased friction. The values given in Table 38 are intended for spillways of this type. "Depth of weir notch" and "length of weir notch" in Table 37 correspond roughly to "head on crest" and "length of spillway" in Table 38.

TABLE 38.—DISCHARGE CAPACITY IN CUBIC FEET PER SECOND OF BROAD CRESTED SPILLWAYS FOR USE WITH MASONRY DAMS AND SIDE SPILLWAY EARTH DAMS

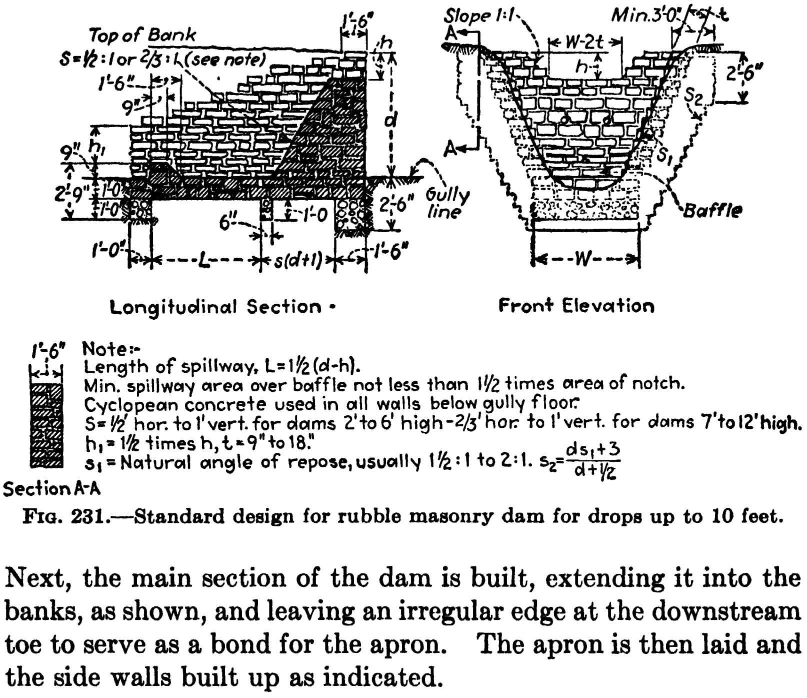
Computed by formula

$Q = 3.2LH^{3/2}$

where Q = discharge in cubic feet per second.
L = length of spillway in feet.
H = head of water on crest of spillway in feet.

Head on crest, feet	Length of spillway, feet													Head on crest, feet
	2	4	6	8	10	12	14	16	18	20	22	26	30	
0.5	2.3	4.5	6.8	9.1	11.3	13.6	15.8	18.1	20.4	22.6	24.9	29.4	33.9	0.5
1.0	6.4	12.8	19.2	25.6	32.0	38.4	44.8	51.2	57.6	64.0	70.4	83.2	96.0	1.0
1.5	11.8	23.5	35.2	47.0	58.8	70.5	82.3	94.1	105.8	117.6	129.3	152.8	176.4	1.5
2.0	18.1	36.2	54.3	72.4	90.5	108.6	126.7	144.8	162.9	181.0	199.1	235.3	271.5	2.0
2.5	25.3	50.6	75.9	101.2	126.5	151.8	177.1	202.4	227.7	253.0	278.3	328.9	379.5	2.5
3.0	33.3	66.5	99.8	133.0	166.3	199.5	232.8	266.0	299.3	332.5	365.8	432.3	498.8	3.0
3.5	41.9	83.8	125.7	167.6	209.5	251.4	293.4	335.3	377.2	419.1	461.0	544.8	628.6	3.5
4.0	51.2	102.4	153.6	204.8	256.0	307.2	358.4	409.6	460.8	512.0	563.2	665.6	768.0	4.0
4.5	61.1	122.2	183.3	244.4	305.5	366.6	427.7	488.8	549.8	610.9	672.0	794.2	916.4	4.5
5.0	71.6	143.1	214.7	286.2	357.8	429.3	500.9	572.4	644.0	715.5	787.1	930.2	1,073.3	5.0
5.5	82.6	165.1	247.7	330.2	412.8	495.4	577.9	660.5	743.0	825.6	908.2	1,073.3	1,238.4	5.5
6.0	94.1	188.2	282.2	376.3	470.4	564.5	658.6	752.6	846.7	940.8	1,034.9	1,223.0	1,411.2	6.0
6.5	106.0	212.1	318.1	424.2	530.2	636.3	742.3	848.4	954.4	1,060.5	1,166.5	1,378.6	1,590.7	6.5
7.0	118.5	237.1	355.6	474.1	592.6	711.2	829.7	948.2	1,066.8	1,185.3	1,303.8	1,540.9	1,777.9	7.0
7.5	131.5	262.9	394.4	525.8	657.3	788.7	920.2	1,051.6	1,183.1	1,314.6	1,446.0	1,708.9	1,971.8	7.5
8.0	144.8	289.7	434.5	579.3	724.2	869.0	1,013.8	1,158.7	1,303.5	1,448.3	1,593.2	1,882.8	2,172.5	8.0

After deciding upon the dimensions to be used for a given location from the data in Fig. 231, the gully floor is excavated to a depth of 1 foot throughout its width crosswise and for a sufficient distance lengthwise to include the longitudinal dam section, and the banks are cut back to a stable side slope. A footing trench 1.5 feet wide and 1.5 feet deeper is dug across the gully and extended up both banks to the top, and the bottom part filled with cement mortar into which "hand size" rock are dropped to make "cyclopean" concrete. The other footing trenches are then dug to the dimensions shown and filled in the same manner.



Longitudinal Section · Front Elevation

Note:-
Length of spillway, $L = 1\frac{1}{2}(d-h)$.
Min. spillway area over baffle not less than 1½ times area of notch.
Cyclopean concrete used in all walls below gully floor.
S = ½' hor. to 1' vert. for dams 2' to 6' high—⅔' hor. to 1' vert. for dams 7' to 12' high.
$h_1 = 1\frac{1}{2}$ times h, t = 9" to 18."
s_1 = Natural angle of repose, usually 1½:1 to 2:1. $s_2 = \frac{ds_1+3}{d+\frac{1}{2}}$

Section A-A

FIG. 231.—Standard design for rubble masonry dam for drops up to 10 feet.

Next, the main section of the dam is built, extending it into the banks, as shown, and leaving an irregular edge at the downstream toe to serve as a bond for the apron. The apron is then laid and the side walls built up as indicated.

The baffle wall shown near the end of the apron is intended to help dissipate the energy of the water flowing past and prevent downstream erosion, but experience indicates that for flows less than the peak, which are the most numerous, the wall has very little beneficial effect. Hence, its use may be considered optional.

416. Concrete Dams.—In localities where suitable stone or rock is not available there is no reason why mass-concrete dams of the same dimensions and general design as shown in Fig. 231 should not be used, except high cost. It is usually better engi-

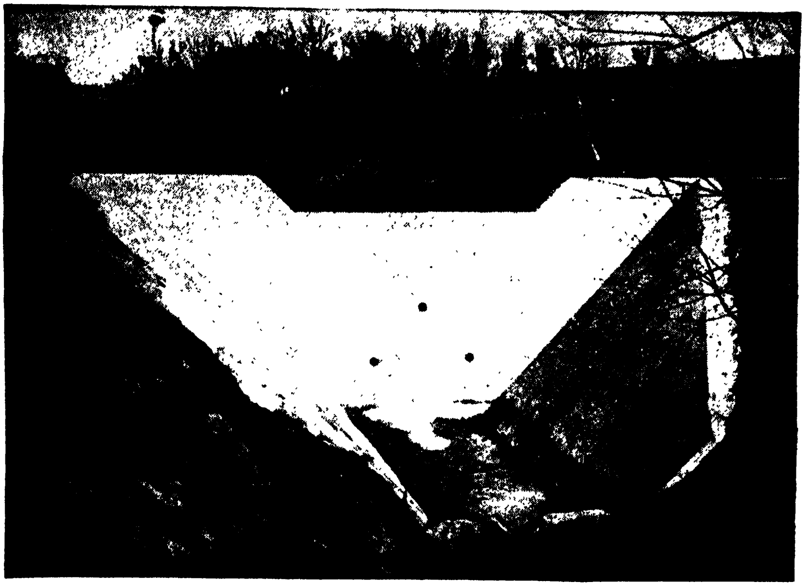


FIG. 232.—Example of Type A reinforced concrete weir-notch dam.

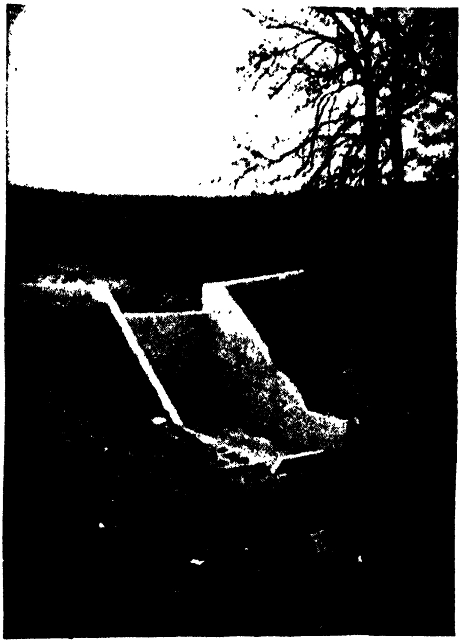


FIG. 233.—Example of Type B reinforced concrete weir-notch dam.

neering, however, to specify thin sections of reinforced concrete in such situations, and this involves radical changes in design.

Two types of reinforced concrete dams are shown in Figs. 232 and 233. Type A is for use in gullies where the cross-sectional area is relatively small in comparison with the watershed area, and practically the entire gully width is needed for the notch or spillway length so as to produce maximum discharge capacity with a minimum depth of flow over the notch or spillway crest. Type B is suited for gullies that have enlarged out of proportion to the watershed drained, where it is possible to contract the cross-sectional area to a figure approximating its original size. In this case a desirable flow depth over the crest can be secured with a relatively short notch.

417. Earth Dams.—Earth dams are of two types, those with overbank spillways and those with drop-inlet culverts. Very often, however, the culverts are designed to care for only ordinary discharges, allowance for excess water being made in the overbank spillway. The values in Table 38 will give the approximate dimensions of spillway required after the run-off has been determined from the curves of Fig. 216, 230, or 237.

Location.—Earth dams should be built where the terrain is such that the influence of the dam will extend over an appreciable area and for a considerable distance upstream, preferably far enough to submerge the overfall at the head of one or more gullies. In estimating the influence distance the stabilized gradients for the various soil conditions previously given (0.5 to 2 per cent) may be used.

The best site for the dam is at a narrow neck with high banks where foundation conditions are good and where the grade of the gully floor is within the limits prescribed for at least 300 feet below the dam. The earth fill should be taken from projecting "knobs" or peninsulas in the gully banks *above* the dam site. All vegetation, stumps, and other foreign material should be plowed up and removed from the foundation before the first fill is placed. As the fill gains height, the earth should be excavated from approximately the same elevation as the point where it is to be unloaded, if at all possible.

The culvert should never be placed on filled soil. It should rest on a stable foundation that is shaped to fit the culvert barrel. The alignment should conform to the center line of the gully below the dam, regardless of where this puts the inlet.

418. Side-spillway Dams.—Dams depending entirely on side spillways to carry run-off should be limited to watersheds of 20 acres or less. Ordinarily the spillway channel must be lined with concrete, corrugated roofing, or some other material more resistant to erosion than vegetation.

Sometimes it is advantageous to place the spillway in the center of the dam if the earth is thoroughly settled and if the cost of a strong structure with seepage curtain walls is justified. As before, the flow dimensions may be taken from Table 38 when the run-off to be discharged is known.

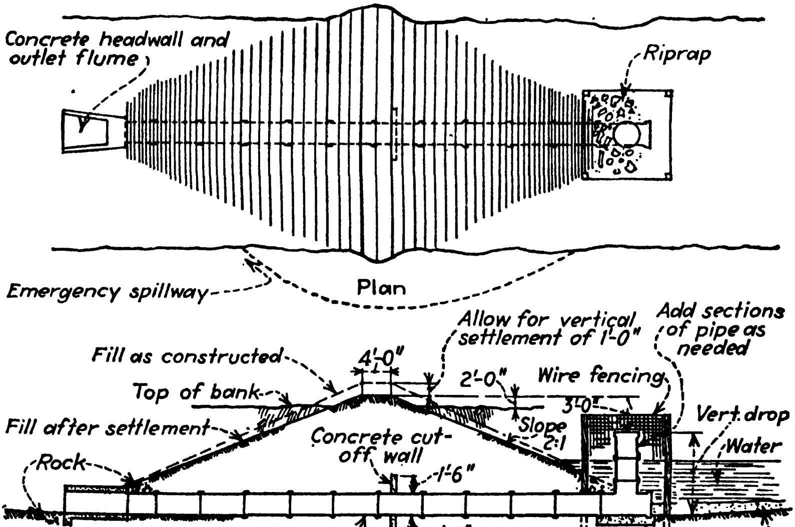


FIG. 234.—Plan and cross-section of earth soil-saving dam with inlet drops of 5 to 15 feet. Concrete pipe or vitrified sewer pipe with cemented bell-and-spigot joints. Culvert gradient not less than 0.5 per cent.

419. Drop-inlet Dams.—Soil-saving dams of the drop-inlet type are structures seldom involving an expenditure of less than $200 for the culvert material alone. Oftentimes the head of water created will run up to 20 or 25 feet, which involves pressures and volumes capable of doing serious damage, or even causing loss of life, in case of failure. Consequently when a structure of this type is contemplated, it is recommended that an engineer experienced in this sort of work be called in to design the dam and supervise its construction. The material that follows is intended to acquaint the landowner with the problems involved and to be of assistance to engineers.

Inlet Drop 5 *to* 15 *Feet.*—For dams with inlet drops of 5 to 15 feet, pipe culverts are usually less expensive than monolithic concrete and are fully as satisfactory when properly installed.

A general plan and a cross-section for dams of this type, using bell-and-spigot pipe made of concrete or vitrified clay, are shown in Fig. 234 which, together with Fig. 235, makes the main construction features evident. Attention is called particularly to the seepage ring or cutoff wall and to the necessity for laying on a firm bedding carefully rounded to fit the bottom quarter of the pipe. The earth fill should be carefully tamped under the haunches and up the sides of the pipe. Additional excavations for the bells should be made so that the pipe is evenly supported throughout its length. When the earth embankment exceeds about 10 feet in height over the top of the pipe, a special study should be made to determine the proper pipe strength to specify.[1] The joints should be caulked with oakum and wiped with cement to insure watertightness.

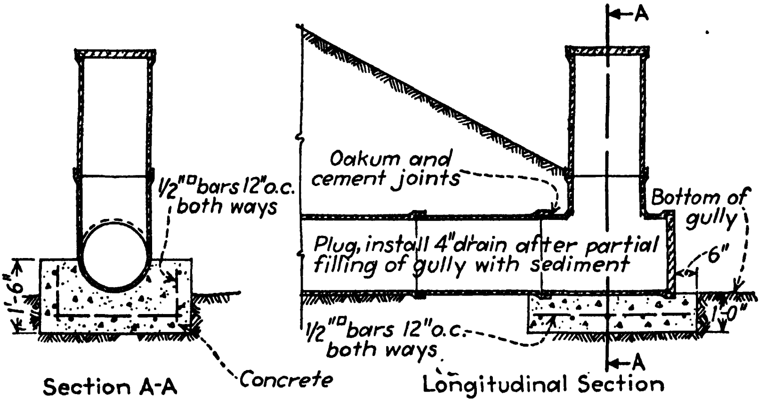

A
1/2"ᴰ bars 12" o.c. both ways
1'-6"
Oakum and cement joints
Bottom of gully
Plug, install 4" drain after partial filling of gully with sediment
6"
1'-0"
1/2"ᴰ bars 12" o.c. both ways
A
Section A-A
Concrete
Longitudinal Section

FIG. 235.—Design details for concrete pipe or vitrified sewer pipe drop-inlet culverts for use with earth soil-saving dams.

One of the best features of rigid pipe dams is the ease with which the riser can be joined to the barrel by use of a standard T-junction, capped on one end with the provision for connecting a line of drain tile after the pondage fill has started to accumulate.

Figure 236 shows an alternate design for installations where corrugated iron pipe is preferred. Only ordinary care is needed in preparing the foundation for this pipe, as it is flexible and will adapt itself readily to slight irregularities in load or in support. The important structural feature is to tamp the earth thoroughly under the haunches and up the sides of the pipe, so that when the load is transmitted to the side fill only a moderate deflection is permitted. Experience has indicated that no cutoff wall is needed with corrugated pipe, as the irregular line of contact formed by the corrugations with the surrounding earth does not permit seepage flow under the heads recommended. Reasonable watertightness is assured by following the directions in the note in Fig. 236. The culvert barrel may be shop riveted in one piece, or it may be obtained in sections of any length, forming multiples of 2 feet, which are securely joined in the field by the use of standard connecting bands and cinch bolts or by field riveting if the diameter exceeds 36 inches.

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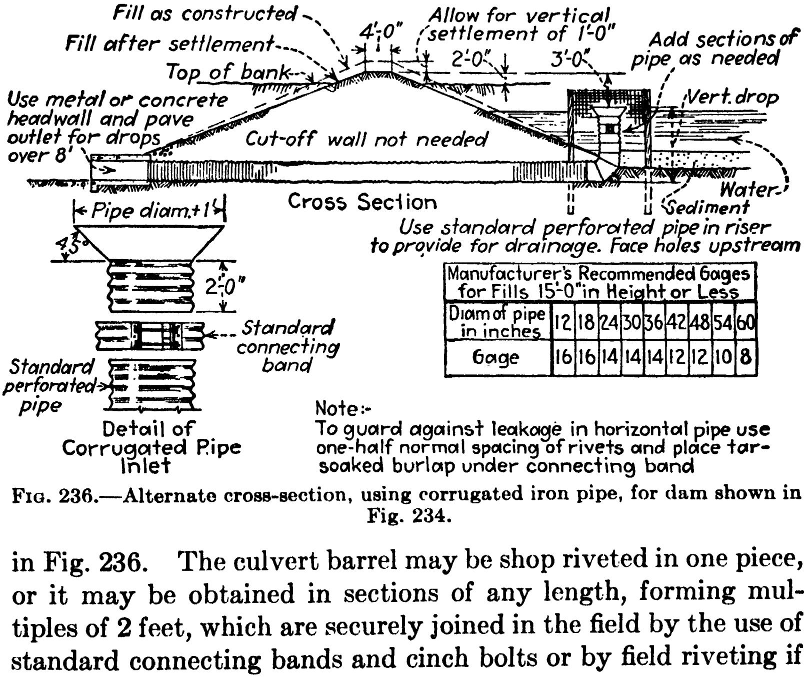
[1] See various bulletins of the Ia. State Coll. Eng. Exp. Sta., particularly Nos. 93, 96, and 112.


Fill as constructed
Fill after settlement
Top of bank
4'-0"
Allow for vertical settlement of 1'-0"
2'-0"
3'-0"
Add sections of pipe as needed
Use metal or concrete headwall and pave outlet for drops over 8'
Cut-off wall not needed
Vert. drop
Water
Sediment
Pipe diam.+1'
Cross Section
Use standard perforated pipe in riser to provide for drainage. Face holes upstream
45°
2'-0"
Standard connecting band
Standard perforated pipe
Detail of Corrugated Pipe Inlet

Manufacturer's Recommended Gages for Fills 15'-0" in Height or Less

Diam of pipe in inches	12	18	24	30	36	42	48	54	60
Gage	16	16	14	14	14	12	12	10	8

Note:-
To guard against leakage in horizontal pipe use one-half normal spacing of rivets and place tar-soaked burlap under connecting band

FIG. 236.—Alternate cross-section, using corrugated iron pipe, for dam shown in Fig. 234.

The junction between barrel and riser should be formed by a 90° metal elbow with 2-foot sections of pipe riveted to each end. The barrel end is connected by a band to the culvert, and the riser end is banded to the funnel inlet shown in the drawing.[1] Whenever it is desired to increase the height of the riser, the funnel is removed and reconnected to an additional

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[1] The Wisconsin model tests indicated the most efficient flare to be one whose maximum diameter is twice that of the pipe and whose depth is equal to the pipe diameter. For risers up to 18 inches in diameter this flare is preferable to the design shown in Fig. 236.

TABLE 39.—CROSS-SECTIONAL AREAS REQUIRED FOR DROP-INLET PIPE CULVERTS

Watershed area in acres	Cross-sectional area of culvert in square feet					
	Rolling land			Hilly land		
	Cultivated C = 1.0	Pasture 0.6	Woods 0.3	Cultivated 1.4	Pasture 0.8	Woods 0.4
1	1.9	1.1	0.6	2.7	1.5	0.8
2	2.1	1.3	0.6	2.9	1.7	0.8
4	2.5	1.5	0.8	3.5	2.0	1.0
6	2.9	1.7	0.9	4.1	2.3	1.2
8	3.4	2.0	1.0	4.8	2.7	1.4
10	3.8	2.3	1.1	5.3	3.0	1.5
15	4.8	2.9	1.4	6.7	3.8	1.9
20	5.8	3.5	1.7	8.1	4.6	2.3
30	7.8	4.7	2.3	10.9	6.2	3.1
40	9.7	5.8	2.9	13.6	7.8	3.9
50	11.5	6.9	3.5	16.1	9.2	4.6
75	15.9	9.5	4.8	22.3	12.7	6.4
100	20.0	12.0	6.0	28.0	16.0	8.0
125	23.8	14.3	7.1	33.3	19.0	9.5
150	27.3	16.4	8.2	38.2	21.9	10.9
200	33.7	20.2	10.1	47.2	27.0	13.5
250	39.4	23.6	11.8	55.2	31.5	15.8
300	44.4	26.6	13.3	62.2	35.5	17.8
350	48.9	29.3	14.7	68.5	39.1	19.6
400	53.0	31.8	15.9	74.2	42.4	21.2
500	60.0	36.0	18.0	84.0	48.0	24.0
600	65.8	39.5	19.7	92.1	52.6	26.3
700	70.8	42.5	21.2	99.1	56.6	28.3
800	75.0	45.0	22.5	105.0	60.0	30.0

Values computed by Ramser formula,

$$a = c\left(130 - \frac{77,000}{A + 600}\right)$$

where a = cross-sectional area of culvert in square feet.
A = watershed area in acres.
c = coefficient depending on nature and type of watershed.

Formula not recommended for areas larger than given in table.

Use above values for vertical drop through culvert up to 5 feet.

Multiply above values by 0.71 for drop through culvert = 10 feet.

Multiply above values by 0.58 for drop through culvert = 15 feet.

For fan- or square-shaped watersheds multiply above values by 1.25.

If side spillway of appreciable capacity is provided, reduction of culvert area may be made accordingly.

2-foot section of pipe. To facilitate drainage of the pondage fill, standard perforated pipe should be used for the 2-foot section riveted to the riser end of the elbow (holes facing upstream), and each alternate section added thereafter should be perforated.

According to the best available information, the average life of plain, galvanized corrugated pipe is estimated at from 20 to 40 years, depending mainly upon the analysis of the base metal. Under special conditions and for individual culverts this life may vary widely up or down. In particularly severe situations, corrugated pipe with a pavement of special-analysis asphalt entirely filling the corrugations of the invert, and fully coated inside and out, is available at a higher price.

For culverts of the design shown in Figs. 234, 235, and 236, Table 39 may be used to determine the required cross-sectional area. When this is known, Table 40 will give the proper diameter. When required areas are intermediate, as they usually are, the next commercial size larger should be chosen. It should be noted that the quantities shown in Table 39 are maximum values, which may be reduced under the conditions mentioned in the table unless the watershed is of unusual shape. The values in Table 39 are based on an empirical formula developed by C. E. Ramser, Senior Drainage Engineer of the U. S. Department of Agriculture, after long experience in observing and measuring run-off from agricultural land in many parts of the United States under a wide variety of conditions. No empirical formula ever devised, however, can be expected to fit perfectly any and all situations. Readers who understand hydraulics should have no

TABLE 40.—CROSS-SECTIONAL AREAS CORRESPONDING TO VARIOUS PIPE DIAMETERS

Diameter, inches	Area, square feet	Diameter, inches	Area, square feet
8	0.349	42	9.621
10	0.545	48	12.566
12	0.785	54	15.904
15	1.227	60	19.635
18	1.767	66	23.758
21	2.405	72	28.274
24	3.142	78	33.183
30	4.909	84	38.485
36	7.069	96	50.265

difficulty in finding the proper size pipe by their own calculations after having determined the required run-off by the methods already given.

To illustrate the use of Tables 39 and 40, let it be assumed that a pipe-culvert dam with an inlet drop of 12 feet (approximately 4 sections of sewer-pipe riser, or 5 sections of corrugated pipe) is to serve an ordinary watershed of 25 acres of rolling cultivated land. Interpolating between 5.8 square feet for 20 acres and 7.8 square feet for 30 acres, 6.8 square feet is obtained. Interpolating likewise between a multiplying factor of 0.71 for a 10-foot drop and 0.58 for a 15-foot drop, 0.66 is found to be the factor corresponding to a 12-foot drop. Multiplying 0.66 by 6.8 gives 4.491 square feet as the proper cross-sectional area. The nearest commercial size from Table 40 is a 30-inch pipe with an area of 4.91 square feet. Therefore, a 30-inch culvert of either concrete, vitrified clay, or corrugated pipe should be used for the conditions assumed. Two lines of 30-inch pipe would accommodate a similar area of more than 50 acres, or a single larger size could be used.

In case the watershed is made up partly of rolling and hilly land and is part pasture and woodland, the same method as that previously described should be followed.

Inlet Drops 10 *to* 25 *Feet.*—For dams developing heads from 10 to 25 feet, it is desirable to use monolithic concrete in a box-type culvert and riser with an inlet of a special design based on recent model tests at the University of Wisconsin. These tests indicated that it would be permissible to place the specially designed inlet much closer to the crown of the dam than had hitherto been considered good practice. Also, by the use of special inlets, rounded junctions, flared outlets, and heads equal to 1.5 times the riser diameter over the inlet lip, a draft-tube effect was developed in the culvert barrel that increased the discharge capacity far beyond that ordinarily expected. This fact, coupled with the shorter length of culvert, should result in real economy over the usual orthodox design. This advantage is offset, to a certain extent, by the necessity for precise adherence in construction to the prescribed design and by the possibility that flood débris may get into the riser stack and interfere with the draft-tube action. Moreover, a large factor of safety is desirable because of the high heads created and the great damage that would follow failure.

These considerations make it desirable to base run-off requirements on greater rainfall-recurrence intervals than those previously recommended. Varying conditions involved in the design of each individual structure of the type here considered demand the exercise of expert judgment in the choice of the proper frequency to apply in any given case. Probably the upper limit will not exceed 50 years, and this is the basis of the run-off curves shown in Fig. 237. Values intermediate between Fig. 237 and Fig. 230 can be interpolated with fair approximation when circumstances seem to warrant.

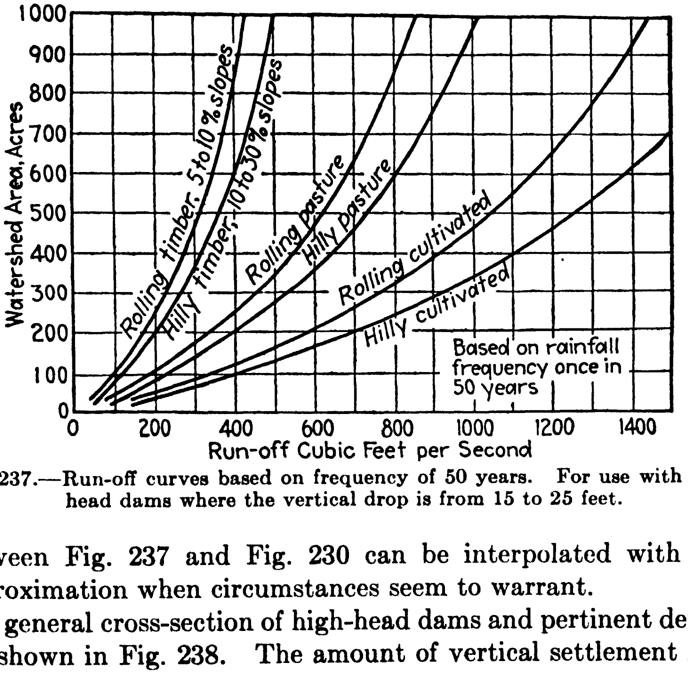


FIG. 237.—Run-off curves based on frequency of 50 years. For use with high-head dams where the vertical drop is from 15 to 25 feet.

A general cross-section of high-head dams and pertinent details are shown in Fig. 238. The amount of vertical settlement S to be allowed varies considerably and will depend upon the type of soil used in the fill, its density, moisture content at the time of placing, care exercised in compacting (placement should be in thin layers thoroughly tamped), and upon other conditions. Rough estimates for normal installations may be assumed as follows: Intermediate values may be interpolated.

$A + D$	Settlement S	
Feet	Feet	Inches
10	1	6
15	2	3
20	3	0
25	4	0

The special design shown in Fig. 238, together with the three sets of head-discharge curves shown in Figs. 239, 240, and 241, represent the best current practice in the use of these dams as

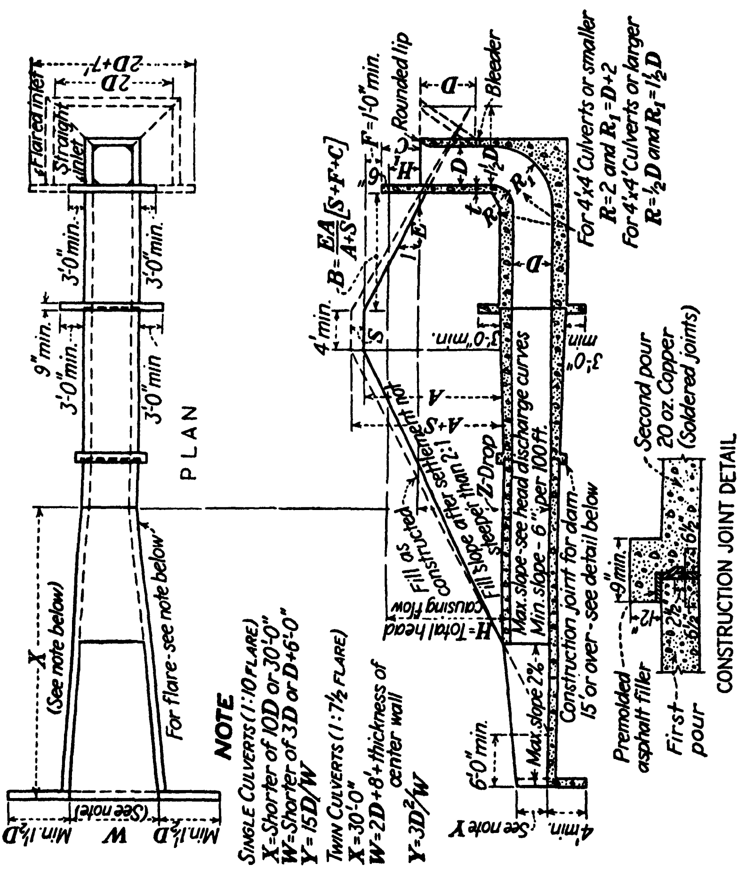
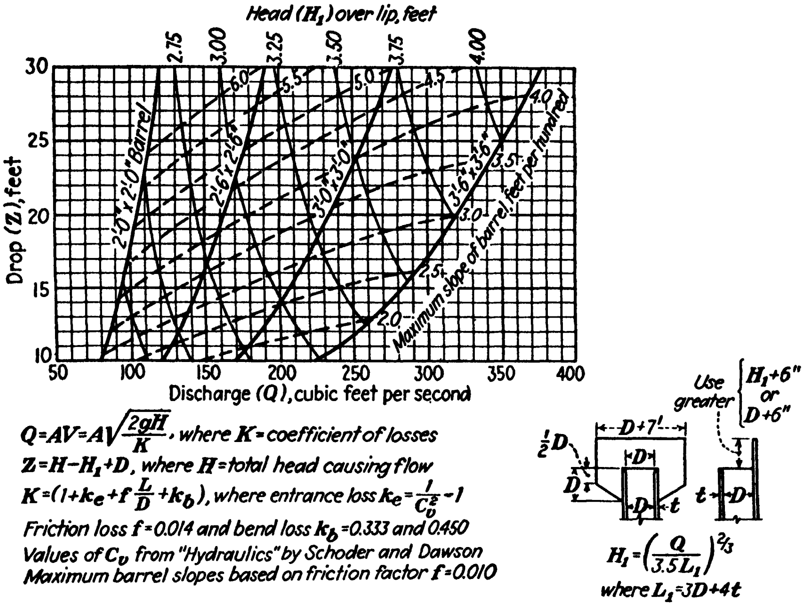

PLAN
2D+T'
2D
Flared inlet
Straight inlet
3'-0" min.
9" min.
X (See note below)
For flare-see note below
Min. 1½D
W
(See note)
NOTE
Single Culverts (1:10 flare)
X=Shorter of 10D or 30'-0"
W=Shorter of 3D or D+6'-0"
Y=15D/W
Twin Culverts (1:7½ flare)
X=30'-0"
W=2D+8"+thickness of center wall
Y=3D²/W
B=EA/(A+S)[S+F+C]
F=1'-0" min.
Rounded lip
Bleeder
H
D
½D
R
R₁
t
E
4' min.
S
V
S+V
3'-0" min.
Fill as constructed
Fill slope after settlement not steeper than 2:1
Z-Drop
H=Total head causing flow
Max. slope-see head discharge curves
Min. slope-6" per 100 ft.
Construction joint for dam-15' or over-see detail below
Max. slope 2%
6'-0" min.
4' min.
See note Y
For 4'x4' Culverts or smaller R=2 and R₁=D+2
For 4'x4' Culverts or larger R=½D and R₁=1½D
CONSTRUCTION JOINT DETAIL
Premolded asphalt filler
First pour
Second pour
20 oz. Copper (Soldered joints)
9" min.
½"
2½"
6½"

FIG. 238.—Special design for high-head dams using reinforced concrete, draft-tube culvert and riser.

interpreted by C. L. Hamilton in an unpublished thesis on file at Iowa State College. According to Hamilton:

> Soil Conservation Service engineers working with the University of Wisconsin engineers have done more detailed experimentation and developed more complete designs on drop-inlet structures than have engineers in other states. In addition, they have constructed large numbers of these dams and observed them under actual field conditions. For these reasons it is felt this compilation of their material will be of



$Q = AV = A\sqrt{\frac{2gH}{K}}$, where K = coefficient of losses

$Z = H - H_1 + D$, where H = total head causing flow

$K = (1 + k_e + f\frac{L}{D} + k_b)$, where entrance loss $k_e = \frac{1}{C_v^2} - 1$

Friction loss $f = 0.014$ and bend loss $k_b = 0.333$ and 0.450

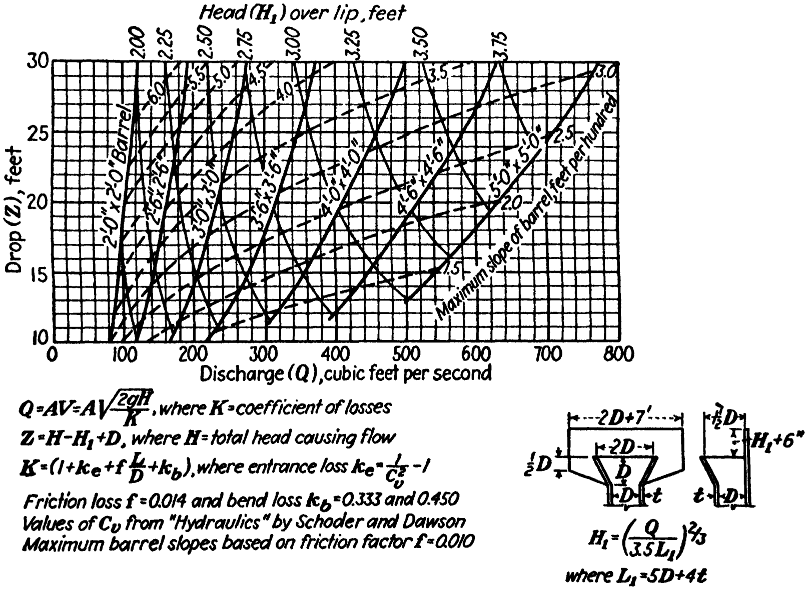
Values of C_v from "Hydraulics" by Schoder and Dawson

Maximum barrel slopes based on friction factor $f = 0.010$

$H_1 = \left(\frac{Q}{3.5L_1}\right)^{2/3}$

where $L_1 = 3D + 4t$

FIG. 239.—Head-discharge curves for single culverts with straight inlets. For use with design shown in Fig. 238.



$Q = AV = A\sqrt{\frac{2gH}{K}}$, where K = coefficient of losses

$Z = H - H_1 + D$, where H = total head causing flow

$K = (1 + k_e + f\frac{L}{D} + k_b)$, where entrance loss $k_e = \frac{1}{C_v^2} - 1$

Friction loss $f = 0.014$ and bend loss $k_b = 0.333$ and 0.450

Values of C_v from "Hydraulics" by Schoder and Dawson

Maximum barrel slopes based on friction factor $f = 0.010$

$H_1 = \left(\frac{Q}{3.5L_1}\right)^{2/3}$

where $L_1 = 5D + 4t$

FIG. 240.—Head-discharge curves for single culverts with flared inlets. For use with design shown in Fig. 238.

value to engineers in other states where the use of this type of structure may be practical.

In view of the diagrams and charts heretofore explained, it is believed that no difficulty will be experienced in making use of the accompanying drawings. A careful study will show them complete in every detail with self-evident usage.

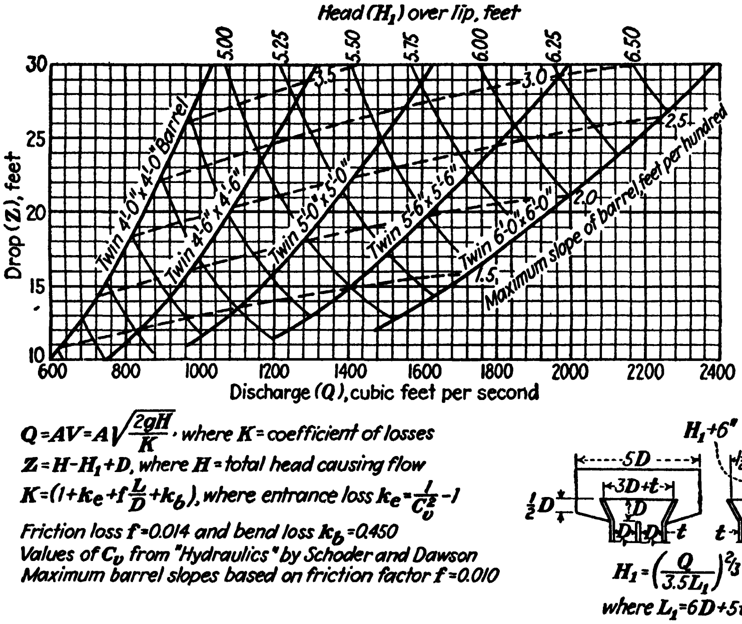


FIG. 241.—Head-discharge curves for twin culverts with flared inlets. For use with design shown in Fig. 238.

420. Pondage Fill.—It is surprising how rapidly fills accumulate behind soil-saving dams, where high heads are used and large areas impounded. An examination of Fig. 242, which is an accurate profile of the center line of two gullies drawn to scale, shows that a fill of more than 1 foot per year occurs in the long gully throughout its length. The high dam shown in the short gully is a side-spillway dam, and the profile shows its pond to be filling at a rate of 2 feet per year. This pond has silted half full in 2½ years.

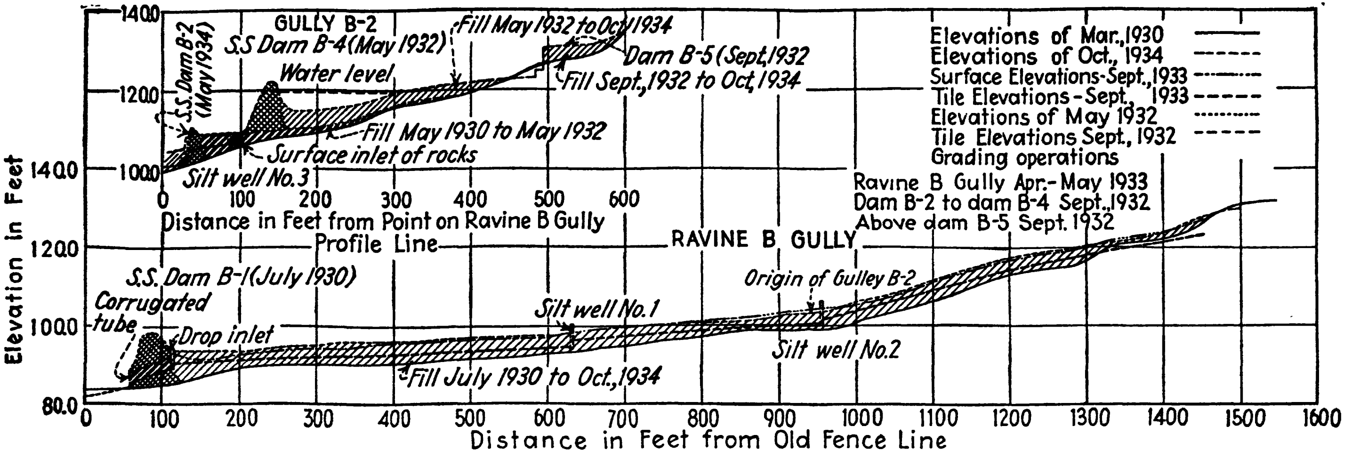
On an inspection tour of Wisconsin in 1933, the author observed numerous fills behind earth dams that had accumulated at a still higher rate. In Buffalo County, Wis., a fill 17 feet deep had been deposited in less than 5 years. These fills are expedited by building diversion ditches or terraces on the high ground above the gully heads to conduct water to the "points" or peninsulas at the junction of lateral gullies and thus hasten the resumption of agricultural operations on "made land" at a lower level than that which originally existed.

Another method of speeding up reclamation is to lay a tile drain up the center line of the gully soon after the initial fill has been caught, cut back the banks to form flat side slopes with dynamite or earth-moving equipment, and till, fertilize, and seed the entire gully cross-section to clover, alfalfa, or some similar crop.

421. Storage Dams.—It sometimes happens that gullies are working their way back into otherwise good permanent pasture land in locations where a supply of water for livestock is needed. If the watershed is not too large, an earth dam with a relatively small tile line to serve as a "bleeder pipe" may be just the thing. The volume of storage required can be computed by taking the difference between the inflow from storms of maximum intensity for the frequency period chosen and the outflow for the same period as represented by the discharge of the tile when the water is midway between the elevation of the inlet lip and its maximum height. The effective gradient (S in Manning's formula) in this case is the slope of a line joining the water surfaces at the inlet and outlet ends of the tile. It is always desirable to provide sodded spillways to serve as a factor of safety against inaccuracy in necessary assumptions used in formulæ and to take the excess discharge from very rare storms.

422. Drop Inlets on Existing Culverts.—One way of gaining great benefit at low cost is to erect drop inlets on existing highway culverts in situations where drop inlets are needed and can be built without subjecting the road embankment to undue hazard. The maximum estimated flow elevation should be kept at least 4 feet below the highway grade.

Many drop inlets have been built as a part of the original culvert design for improved highways, but a vastly greater number of opportunities exist for belated installations, especially along secondary roads.



PROFILE OF RAVINE B GULLY AND NORTH BRANCH B-2 SHOWING RECLAMATION PROGRESS OVER A FOUR YEAR PERIOD, 1930-1934
SOIL EROSION EXPERIMENT FARM-BETHANY, MISSOURI

FIG. 242.

A typical view of such an inlet is shown in Fig. 243. In designing the structure it may be considered a broad crested weir, the required crest length being taken from Table 38 when the anticipated run-off and permissible flow depth are known.[1]

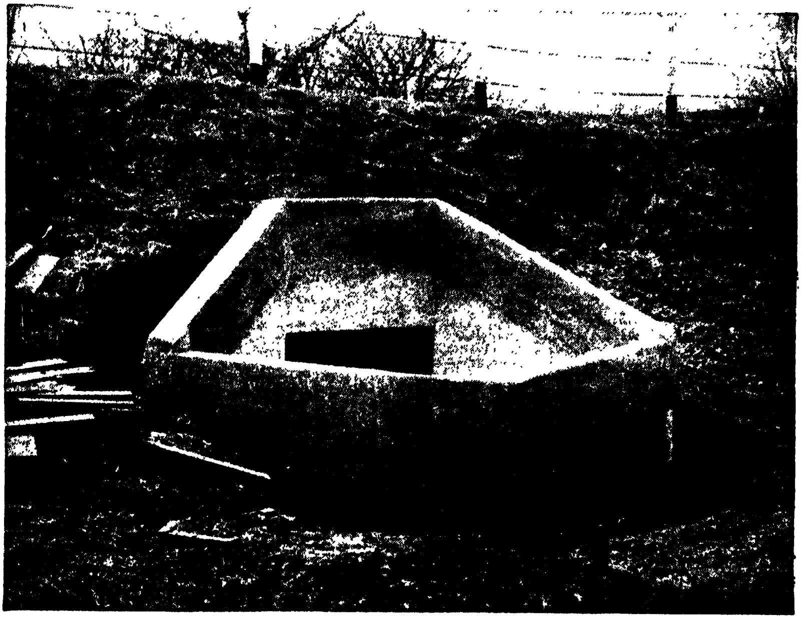


FIG. 243.—Existing culvert under paved highway in Page County, Iowa, converted into a drop-inlet structure by enclosing the wings with a curtain wall. (*Courtesy of U. S. Bureau Agr. Eng.*)

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[1] For a complete discussion of the hydraulics of head spillways with low drops, the reader is referred to *Univ. Wis. Research Bull.* 122.

CHAPTER XXIV

SUBSURFACE DRAINAGE

423. Object of Subsurface Drainage.—The object of subsurface drainage is to lower the water level below the surface of the ground and hold it in as nearly a constant position as possible. Surface drainage is necessary to take the water off the surface and eventually to receive the waters from subsurface drains. Means used to accomplish subsurface drainage are surface ditches, poles, stones, and tile drains.

424. Nature's Method.—Where the soil structure is such that there is a water-collecting layer of sand or gravel from 2 to 5 feet below the surface of a rich top soil, there is, as a general rule, no need of any artificial method of subsurface drainage; however, the thoroughness of such drainage depends on how readily the sand or gravel will take up the surplus water and on the rate at which it passes through the surface soil.

FIG. 244.—"Sink hole" on a farm in New York.

425. Surface Ditches.—The idea that open or surface ditches, used to take off surface water, are effective subsurface drains is more or less prevalent. In a sandy or open soil, there is no doubt that these ditches do tend to lower the water level below the surface. But in a clay or heavy soil, the sides of the ditch soon become puddled by the action of the water, thus sealing them against any water seepage through their banks. Land which is subject to water standing over its surface can be materially helped by putting small V-shaped surface ditches at frequent intervals, and where the soil is open, even better results can be obtained, resulting in a great improvement in the crops raised. But this method of subsurface drainage should be practiced only for a limited period and should be abandoned for tile as soon as funds are available.

426. Use of Poles.—Before the advent of tile, farmers dug ditches 2 or 3 feet deep and 1 foot wide in which were placed three poles. These poles were arranged in the shape of a triangle. The ditches were then filled up. They were given an outlet into an open ditch. The water would seep in around the poles and flow along the poles to the open ditch. This method was more or less temporary, because, as soon as the poles decayed, the dirt fell in and stopped up the drain. The outlay of money was small, however, because the poles could, as a rule, be cut on the farm, and the ditch dug by the farm hands during a slack time. This method is practiced to some extent in the South today, but it is not to be advocated except where the money for the tile is not available, as it is poor economy. The digging of the ditch is the most costly part of the enterprise even when tile is bought, and, therefore, a material as durable as possible should be used in the bottom of the ditch in order to eliminate the expense of digging the ditch again.

FIG. 245.—Dead furrow drainage.

427. Use of Stones.—Drainage by the use of stones was accomplished in the same manner as by poles. If large, flat stones were available, they were placed at the sides of the ditch with one over the top, thus forming a small channel which was more durable than the poles. If flat stones were not to be had, small stones were thrown into the ditch to the depth of 6 or 8 inches. The water percolated around them to the outlet. In many parts of the country, there are no stones available for this method, and, even if they are available, the method is not to be advocated, for the same reason that the use of poles was said to be inadvisable. Instead of the poles decaying, in this case, the spaces between the stones become clogged with silt, thus rendering the drains useless.

FIG. 246.—A New England farm provided with subsurface drains 40 feet apart.

428. Use of Tile.—This is the most efficient method. The tiles are used in the same way as the poles and stones were used. They are more durable when properly put in and should last for many years, doing good work.

In the following discussion of subsurface drainage, only the method of installing tile will be discussed. The other ways are either obsolete or confined to special cases and are not at all important.

429. Benefits of Subsurface Drainage.—Subsurface drainage results in lowering the surplus or gravitational water level from 2 to 4 feet below the surface of the ground. As the water percolates down to the tile, air is drawn into the soil to take its place. This is called *soil aeration.* Drainage has three major beneficial effects: (1) It gives the root zone greater depth, which increases the available supply of plant food and moisture. It has been found that plant roots will extend as far as 3 or 4 feet below the surface of the ground where conditions are favorable. (2) It results in a warmer soil. Water-logged soils are slow to warm up, because more heat is required to raise the temperature of a given volume of water 1° than to raise the temperature of a like volume of air the same amount. When air is in the soil in place of water, therefore, the soil warms up more quickly and maintains a higher average temperature. This allows earlier planting of crops and lengthens the growing season. (3) The physical condition of the soil is improved. Wet soils, especially clays, are hard to handle if soil puddling is not avoided. Drainage permits the development of the granular structure so essential to good tilth and lengthens the period during which the optimum soil moisture content prevails. Drained land is, therefore, more safely and easily worked, reducing the effort of the farm operations.

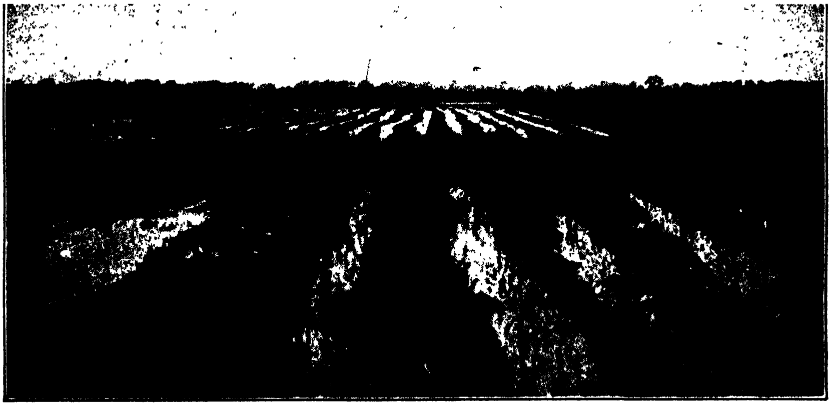


FIG. 247.—A field badly in need of both surface and subsurface drainage.

Interlinked with the three major benefits given above are several outstanding benefits that become very noticeable to the farmer. It will, perhaps, be well to examine these a little more in detail. The aeration and higher temperature due to drainage increase the activity of soil organisms, by whose efforts the plant food of the soil is rendered available. The improved physical condition of the soil results partly in an increased ability of the soil to retain a larger amount of film water which, in dry periods, increases the supply available to plants. There is, also, a better internal circulation of water through the soil. The accumulation of toxic substances in the soil is greater where poor drainage conditions prevail. Sanitary soil conditions often form one of the problems of good management. The formation of these toxic substances is less in well-drained soils.

The removing of the surplus water from the soil eliminates dampness, which reduces the vitality of the people and the stock on the farm, rendering them more susceptible to disease. The removal of stagnant water also reduces the danger from malarial troubles. Drainage reduces injury by frost, since air instead of water occupies the interstices of the soil. The heaving action of frost is not so harmful on well-drained soils; this is, of course, more noticeable in the North than in the South. The increase in the depth of the root-system zone enables crops better to withstand conditions of drought.

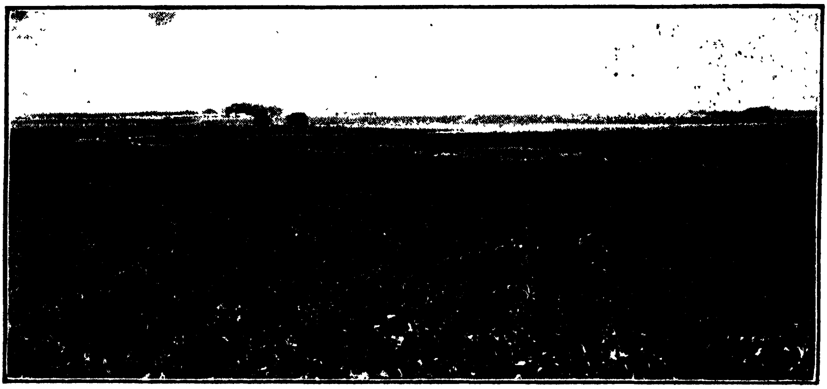


FIG. 248.—This ditch follows a zigzag course through the corn field greatly increasing the labor and inconvenience of tillage. A moderate-sized tile would carry the water so that every square foot could be worked and made to produce. (*Courtesy of Mason City Brick and Tile Company.*)

Since excess moisture is readily removed by drainage, crops withstand wet-weather conditions better. This is highly important at planting time since it tends to prevent the drowning of sprouting seed.

Soil erosion is reduced by drainage, since much of the surplus water passes out through the tile instead of over the surface. Although the need for commercial fertilizer is reduced on well-drained soils, their efficiency when used is increased by drainage, since they are permitted to sink more deeply into the soil and are less likely to be washed away in the surface or run-off water.

The improved drainage of the surrounding fields maintains the foundations as well as the surface of the farm roads and walks in better condition for travel, thus reducing the expense of upkeep.

If all the benefits are derived from proper drainage, then there will be better crops produced on the farm at a reduced cost of operation. This will mean that the farm will return greater profits. Often, the increase in production for the first year pays for the cost of the tile installing. The increase in production for the years following is clear gain.

The bettering of farm conditions as to sanitation, appearance, and crop yields means that the farm is more valuable; hence, there follows an increase in property value.

Also, the elimination of random wet spots squares up fields and results in a uniform stand of crops, which are, in consequence, produced with less labor and inconvenience.

430. Benefits Dependent on Adequate Surface Drainage.—It is, of course, understood that subsurface drainage is dependent on adequate disposal of the surface water, as it would be difficult to carry out subsurface drainage satisfactorily without an adequate system of surface drainage. If surface drainage were not properly done, the subsurface drains, as ordinarily designed, would not be able to carry all the water, and much of the benefits therefrom would be lost. The results and benefits enumerated above, therefore, while given as those of subsurface drainage, are also dependent upon a good system of surface drainage.

SOIL-WATER CHARACTERISTICS

431. Ground-water Table.—In all soils requiring drainage, there exists at, or just below, the ground surface a zone of saturated soil which is completely filled with water. The elevation to which water will rise in shallow wells dug in such soil delineates the surface of gravitational water, which is variously spoken of as the *ground-water table, plane of saturation,* or simply *surface of ground water.* Since the roots of no field crop will penetrate below the ground-water table, and since the various crops normally produce root systems of different lengths, it is the work of the drainage engineer not only permanently to lower the plane of saturation but also to hold it at some fixed depth best adapted to the needs of the crop to be grown.

At the present time, our scientific knowledge is not sufficient to enable this to be done with mathematical exactness. Good practice, at present, consists mainly in estimating the most desirable elevation on a basis of experience and judgment and then approximating the proper depth and spacing of drains necessary to bring it about. A number of investigations are now underway, however, the purpose of which is to throw more light on this obscure relationship. Pending the outcome of these studies, which may require many years for their consummation, it is well to consider some of the theoretical principles involved in the flow of water through soils.

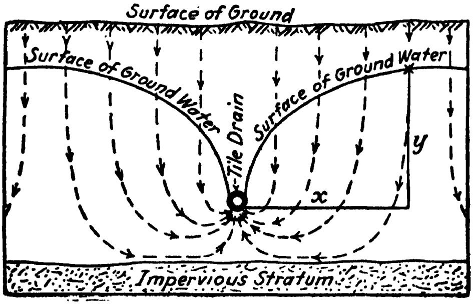


FIG. 249.—Diagram illustrating ideal conditions in drained subsoils.

432. Shape of Ground-water Table.—If a row of wells be dug at right angles to several lines of underdrains, and the elevation to which water rises in each be measured and recorded, the highest point will be found midway between the drains from which the water descends in a gradual slope in both directions. The resulting curve is illustrated by Fig. 249, which also shows the general trend of the path that water is thought to follow in traveling from the ground surface to the drain. Of course, just after a heavy rain, the entire depth of soil is saturated with moving water which drives out stale air below and draws in fresh air above it. That part falling immediately above the drain no doubt passes directly downward and enters the top, while the water between drains follows the direction indicated and enters from the bottom. A few hours after the cessation of rainfall, however, the ground-water table assumes the shape shown which grows flatter day by day until the next rain occurs.

433. Equation of Curve.—In order to predict with precision the minimum depth at which ground water will be held by a given system of drains, it is necessary to know the mathematical equation for the ground-water curve. Many attempts to derive such an equation from field experiments have resulted in failure, due to innumerable irregularities in the texture and structure of the soil and to local obstructions such as wormholes, root cavities, boulders, etc. Again, the height to which the ground-water table will rise after a rain is doubtless influenced to some extent by the action of air entrapped in the soil pores underneath the incoming water. This effect will be more marked following a sudden downpour, which allows little time for diffusion, than it would be in the case of the same amount of water falling at a more gradual rate.

A laboratory investigation, however, recently conducted by Carl D. Gross, under the partial direction of the authors in collaboration with the Engineering Experiment Station of Iowa State College, has brought to light some interesting facts. Though it is too early to draw conclusions of practical value, Mr. Gross has proved tentatively in the course of a 2-years' study that the curves for fine sand are hyperbolic and of the general form

$$y = \frac{x}{a + bx}$$

where (if the origin of coordinates is assumed at the bottom of the drain (see Fig. 249).

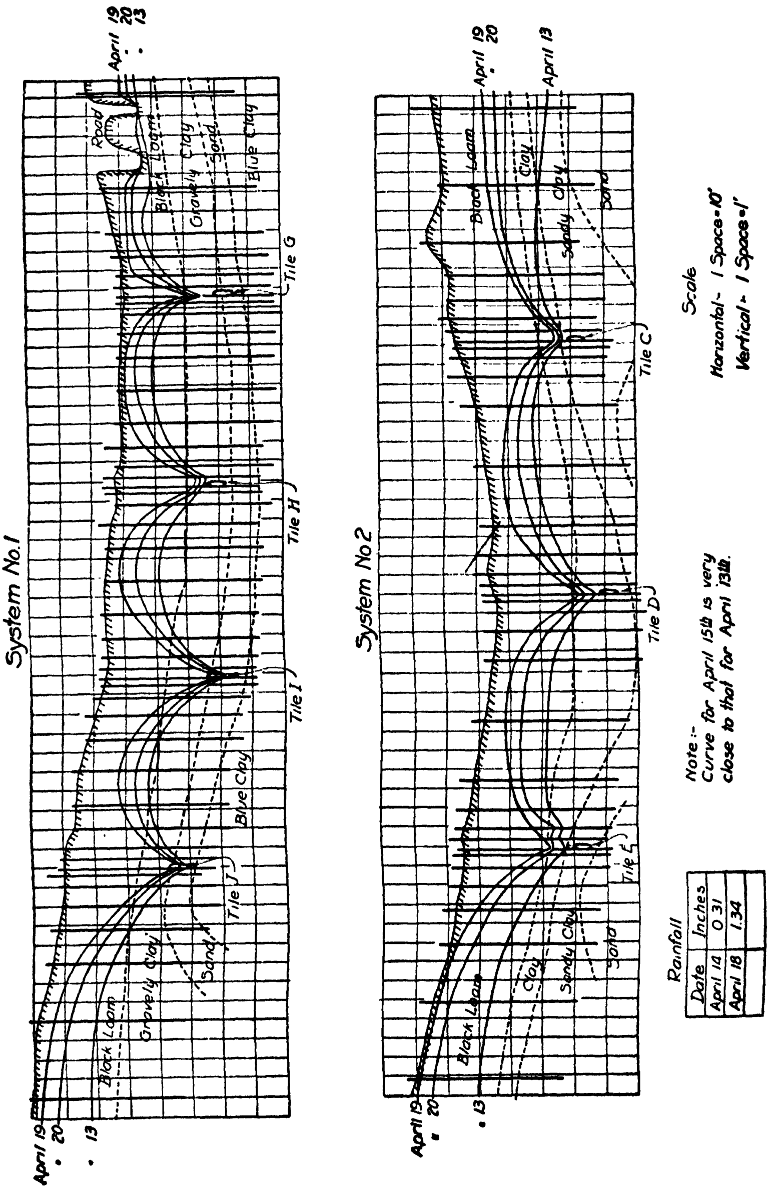
x = abscissa; y = ordinate

a = a constant for a specific curve

b = a constant for a specific curve

Actual Ground-water Curves.—Figure 250 shows several ground-water profiles as they actually occur in field soils and indicates the variations to be expected from the ideal conditions illustrated in Fig. 249.

These curves bring out quite clearly the effect of rainfall on underdrained soils. On Apr. 14, 1909, a rain of 0.31 inch occurred which apparently was entirely absorbed as capillary moisture, since the curve for Apr. 15 is practically identical with the one shown for Apr. 13. The rain of 1.34 inches on Apr. 18 fell on moist soil and was much more than enough to replenish the capillary supply. Consequently, the excess was stored as gravitational water, which raised the water table to the position shown on Apr. 19. By Apr. 20 the tile drains had drawn off enough water to lower the surface of saturation to the elevation indicated on the diagram for that day.



Note:- Curve for April 15th is very close to that for April 13th.

Date	Inches
April 14	0.31
April 18	1.34

FIG. 250.—Typical ground-water profiles. (*Eng. Exp. Sta., Iowa State Coll. Bull.* 52.)

It would appear from a casual study of these graphs that some of the drains of system 1 would have been even more effective had they been placed deeper so as to lie nearer the surface of the blue-clay subsoil. The heavy vertical lines represent the location of the test wells used in determining the position of the ground-water curves.

434. Rate of Flow.—The velocity with which ground water will move between any two points toward a drain depends upon a number of variable factors, chief among which are (1) soil characteristics (which determine the degree of resistance), (2) the difference in elevation between the two points or the amount of fall, (3) the length of the path taken by the water in moving from the high point to the lower, and (4) the temperature of the water. This is applied in the following chapter.

References

ETCHEVERRY, B. A.: "Land Drainage and Flood Protection," McGraw-Hill Book Company, Inc., New York, 1931.

POWERS, W. L., and T. A. H. TEETER: "Land Drainage," John Wiley & Sons, Inc., New York, 1932.

U. S. Dept. Agr. Farmers' Bull. 1606.

CHAPTER XXV

LOCATION OF TILE DRAINS

435. Tile-drainage Terms.—A *main tile drain* is one into which several lines of tile empty their water. Mains are usually of 6-inch tile or larger.

A *submain* is a short main which collects the water from a number of lines of tile and empties it into the main.

A *lateral* is a line of tile which collects the water from the soil and empties it into the main or the submain.

436. Methods of Survey.—The first thing to do in making a survey for tile drains is to go over, either on foot or on horseback, the land to be drained and get a general idea of the following conditions: the wetness of the land; the number and kind of open ditches available for outlets; the high watermark in these ditches; the topography of the land; together with any other details that may be needed in the work. After this reconnaissance, the method of survey can be determined. There are two methods used—one requiring a topographical map as a basis to work on and one that does not require the map. The latter method is employed where no extensive system of drains is to be put in but just one or more drains to clean up wet spots located at well-defined places over the field. These drains can, as a rule, be run in by the eye, and a line of profile levels run over them. But where any extended system of tile drainage is to be installed, it is quite the best thing first to make a topographical map of the field. The advantage of this method is that the map allows the entire farm or field to be seen all at once, while, in the field, only part of it can be seen at a time, and the difference in elevations of all points in the field cannot be recognized. This is particularly true of a field which is fairly flat. Another advantage is that a permanent location of the tile can be kept.

437. Locating Tile with the Topographical Map of the Field.—A careful study should be made of the best way to run the lines of tile and of the system to use. The tile outlet should be placed at the most advantageous point. As few outlets as possible should be put in, because they are expensive both to put in and to keep up. Tile should be given as much fall as possible. The entire system should be plotted on the map. Often several systems will need to be plotted before the most efficient and economical one has been determined. It is generally considered best to run the tile at right angles to the contour lines. Each line of tile should be given a letter or number, in order to distinguish it from the others. Thus, main *A* or *B*, laterals 1, 2, 3, or 4. A given lateral then would be lateral 2 on main *B*, etc. This numbering will be of assistance in labeling profiles and in making a bill of material.

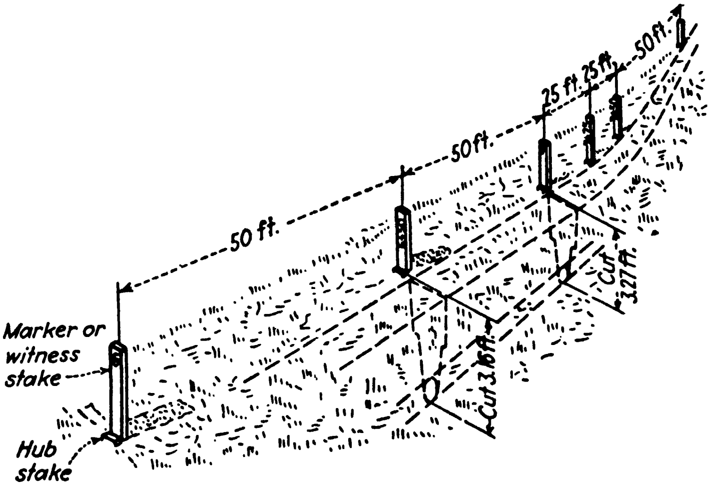


FIG. 251.—Sketch illustrating the customary method of staking out lines for tile drains.

438. Staking Out Drains.—After the tile drains have been located on the map, they should be staked out on the field in the places corresponding to those on the map. Stakes should be driven each 50 or 25 feet, as with profile leveling (Fig. 251).

439. Obtaining Grades.—After the lines of tile are staked out, profile levels are run over each of them. Profiles are plotted. Then, on these profiles, the tile are plotted at the proper depths and with the proper grades. The desirable depths and grades will be discussed later. With the tile plotted on the profile, the cuts can be obtained by getting the vertical distance between the tile line and the ground line (Fig. 252). In this way, the cut at each station can be obtained. This cut should be marked on each stake and recorded in the notebook. It is the depth that the ditch will have to be dug at that point.

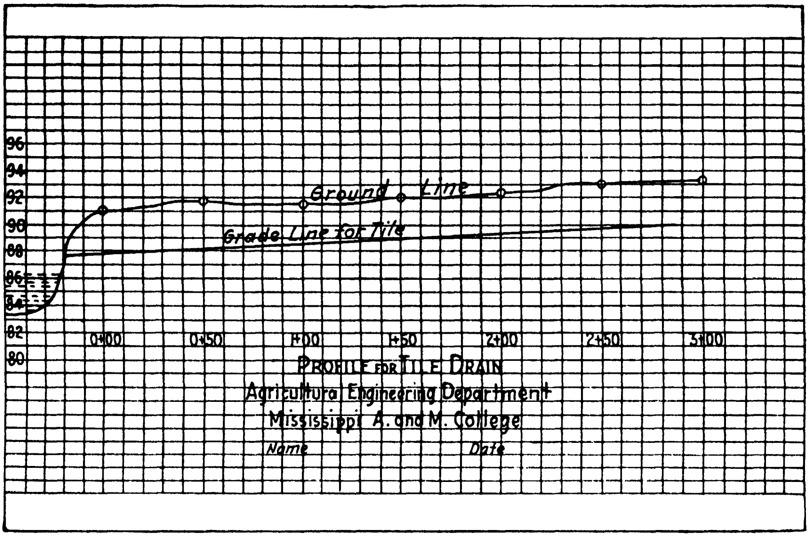


FIG. 252.

440. Systems of Tile Drains.—Definite systems are usually employed in the drainage of land with tile, the natural conditions of the land determining the system to be used. There are eight different systems in general use—the natural, herringbone, gridiron, grouping, Elkington, double main, cutoff, and across-the-slope.

441. Natural System.—This system consists of placing the tile drains in various ways in order to drain certain wet spots in the field (Fig. 253). It should be used only where there are a few depressions which hold water, these remaining wet while the rest of the land drains well.

442. Cutoff System.—This system is used on seepy hillsides where the water comes to the surface and makes the hillsides, as well as the bottoms, wet and unproductive. Tile placed along the hillside intercept this seep water and cut it off, thus preventing it from going onto the bottom (Figs. 254 and 255).

443. Elkington System.—This system was first used by Joseph Elkington of Warwickshire, England, in 1764 (Fig. 256). It is practically the same as the cutoff system and is used for the same purpose—to intercept seepage water—but has, in addition, wells dug at regular intervals to let the water come up from a lower stratum and enter the tile; or, in other words, wells are dug which allow the water to rise to the tile which drains it away. If the earth is not firm enough, these wells can be curbed with lumber or masonry, or filled with gravel. The system is particularly applicable to bogs and springs. It is also used to a considerable extent in the draining of irrigated lands.

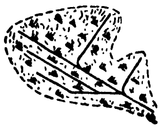


Fig. 253.—Natural system.

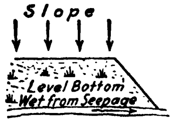


Fig. 254.—Cut off system.

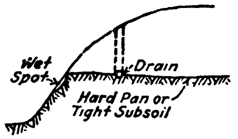


Fig. 255.—Location of tile for draining spouty spots on hillsides.

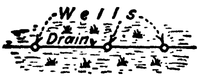


Fig. 256.—Elkington system.

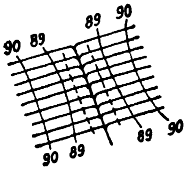


Fig. 257.—Herringbone system.

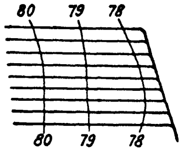


Fig. 258.—Gridiron system.

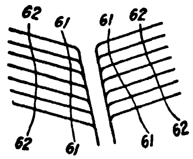


Fig. 259.—Double-main system.

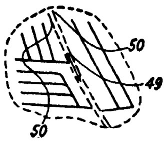


Fig. 260.—Grouping system.

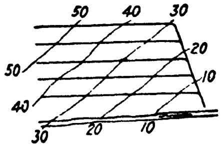


Fig. 261.—Across the slope system.

444. Herringbone System.—The herringbone system is used on a bottom having two sloping sides. The main objection to it is that it involves considerable double drainage. The mains and the ends of the laterals entering the main drain the same land. This is double drainage and not, of course, economical. Figure 257 shows this system, and the distance between the two dotted lines indicates the extent of double drainage.

445. Gridiron System.—This system is shown in Fig. 258. It will be seen that there is not so much double drainage here as there is in the herringbone. It is, therefore, to be preferred to that system wherever a preference is possible.

446. The Double-main System.—This system (Fig. 259) is the same as placing two gridirons together. It should be used where it is desirable to have two lines of small tile in place of one large one in the center. Such a condition might be where there is a slough or boggy place in the center. This system is not used so much as the others, as conditions are not often met that require it.

447. Grouping System.—This system (Fig. 260) consists of collecting the water from a number of small systems and discharging it into the ditch through one outlet.

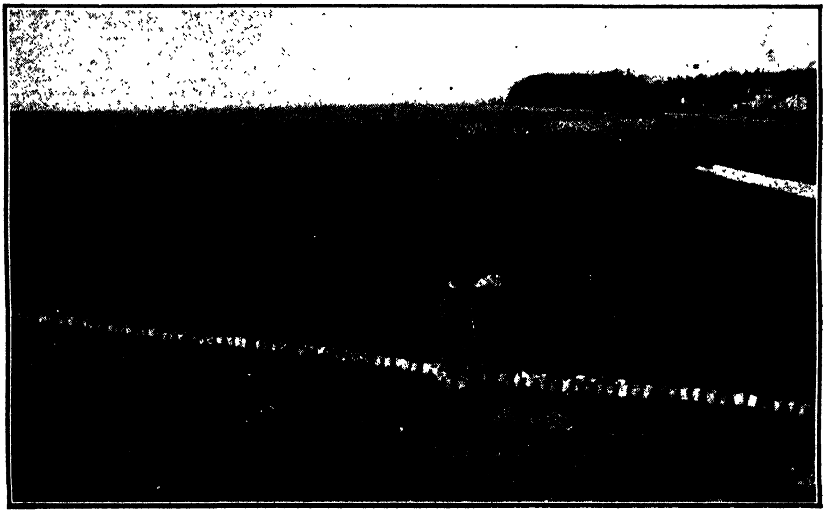


FIG. 262.—Trenches under construction in a field being drained by use of the gridiron system. Note that top soil is placed on one side of the trench and subsoil on the other.

448. Across-the-slope System.—This (Fig. 261) is known also as the *Keythrope system.* It consists of running the lines of the tile across rather than down the slope, the idea being that often the subsoil lies in such a way as not to be free from small valleys which allow the water to flow along the subsoil directly down the slope. Then, if the tile were run across the slope, it would intercept this water and thus more readily drain it. This system has been used with good results where the subsoil is in the condition named above. A soil auger can be used to determine the lay of the subsoil.

449. Selecting the System.—Usually, the condition of the surface of the land makes it possible to use one or more systems.

Below are given a few general principles which will assist the drainer in this selection.

The mains should be put along natural drainage lines. The reason for this is that water naturally runs that way.

Mains and laterals should be, as far as possible, placed in straight lines. Where the directions of these are to be changed, it should be done by long, easy curves. One reason for this is that, in changing the direction of the flow of water, its velocity is lowered. The sediment-carrying power of water depends on its velocity, so if muddy water is slowed up, it drops its sediment and thus fills up the tile, rendering it useless. It is often desirable to cut through small banks in order to keep the lines straight.

FIG. 263.—The herringbone system fits this field better than any other.

Laterals should be given the greatest fall possible by running them down the slope, except in cases of intercepting seep water.

Laterals should be in long lengths rather than short ones, in order to eliminate double drainage due to the mains and laterals' draining the same land.

The system should be selected, and the drains so placed that all the land is equally well drained.

The number of outlets used should be held to a minimum.

In Figs. 264, 265 and 266 are shown three methods[1] of draining a field of 20 acres. The field is 80 rods long by 40 rods wide, with a gradual slope toward a short side of the field. The character of the soil is such as to require a spacing of 50 feet for the laterals. In Fig. 264, a main has been placed lengthwise through the field with the laterals coming in from both sides (herringbone system). In Fig. 265, the main has been placed along one long side of the field 1½ rods from the fence. Laterals enter the main from one side only (gridiron system). In Fig. 266, the main is shown across the lower side, with laterals running lengthwise of the field. This is also a gridiron system. It will be noted that this system has a minimum length of main and a maximum length of laterals.

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[1] *Ohio State Univ. Bull.* 6, Vol. XVII, 1922.

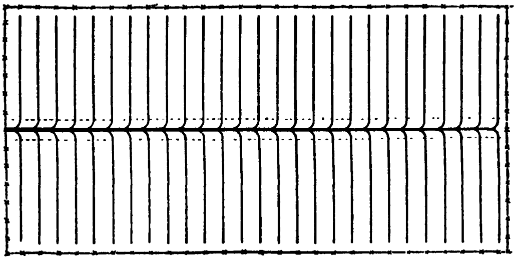

Fig. 264.

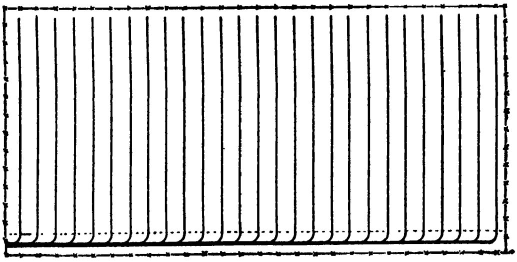

Fig. 265.

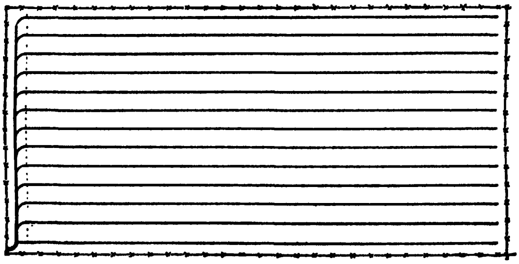

Fig. 266.

A comparison of these three systems with respect to length of main, length of laterals, number of connections of laterals to main, and amount of double drainage is shown in the following table:

	Figure 264	Figure 265	Figure 266
Length of main, rods	80	80	40
Total length of laterals, rods	1,000	1,000	1,000
Number of connections	54	27	13
Amount of double drainage, square rods	240	120	60

For purposes of further comparison, let us assume that the main tile cost $70 per 1,000 feet; 4-inch laterals, $25 per 1,000 feet; digging the trench, laying the tile, and backfilling, 50 cents per rod; and connections, 40 cents each. We then have

	Figure 227	Figure 228	Figure 229
Laterals	$ 412.50	$ 412.50	$412.50
Main	92.40	92.40	46.20
Connections	21.60	10.80	5.20
Trench	540.00	540.00	520.00
Total	$1,066.50	$1,055.70	$983.90

From this, it is seen that the system shown in Fig. 266 will cost $71.80 less than that shown in Fig. 265 and $82.60 less than that in Fig. 264. This is a saving of $4.13 per acre in favor of the gridiron system of Fig. 266. This system is not only the cheapest of the three to install but is also the simplest and best.

Figures 267 and 268 show a field sloping toward an open ditch. In Fig. 267, each lateral empties directly into the open ditch. This means 27 outlets to construct and maintain. Very few farmers will go to the trouble and expense of constructing that number of good concrete outlets. The chances are that each outlet will be left without any protection. The end tile are almost sure to become misplaced or broken and clogged with weeds and soil. A clogged outlet always means poor drainage, as no tile line is any better than its outlet.

In Fig. 268, a main has been placed parallel to the open ditch and empties into it at the lower end of the field. This system will require no more rods of trench or tile than that in Fig. 267, for the number of rods of laterals saved will equal the number of rods of main required. About the only additional expense of putting in the main is the difference in cost of the main over the 4-inch laterals. This difference will be saved many times over in having but one outlet to construct and maintain, and it is extremely cheap insurance for the drainage system.

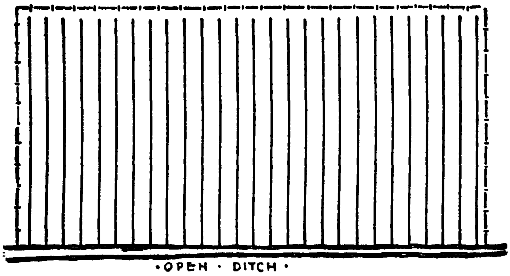

FIG. 267.

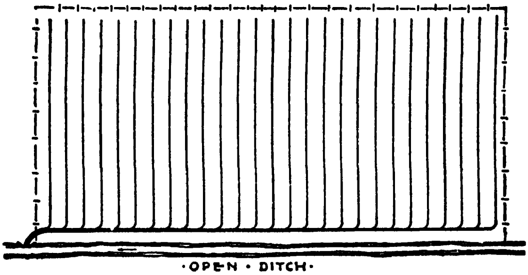

FIG. 268.

450. Theory of Spacing and Depth of Tile Drains.—Consider two lines of tile both placed at a given depth *D* (Fig. 269) and spaced a certain distance apart. The function of the tile is to collect and carry away surplus ground water. Rain falling directly over the tile or at the points *A* will, owing to gravity, work through the soil until it reaches the tile, through which it will flow away. The water which falls on the ground at some points *B*, to one side of the tile, will not flow directly to the tile but, owing to action of gravity, will work down in a vertical direction, such as along the line *BB'*. To reach the tile this water would have to move horizontally, but, since it cannot flow in that direction by gravity alone, it must remain relatively stationary until more water "stacks up" above it. When this occurs to a sufficient extent the weight of the higher water will exert pressure and force the water in the vicinity of the line *XX* to move sidewise toward the drains along paths of least resistance.

Upon arrival, it is forced upward and enters the tile through the lower portion of the joints, or openings between individual tile, whence it flows away inside the tile by gravity. After the rain stops, flow will continue toward the drains at a constantly decreasing rate until finally all movement will cease when the height of the "stack water" is just sufficient to balance the resistance at any given point.

Take the point *C*: Water falling on the surface here works downward toward the line *XX* and then must travel laterally toward the tile. Obviously, more pressure is required to force water to the tile from the point *C′* than from the nearer point *B′*. It follows that the height of the "stack water" must be correspondingly greater at *C* than at *B*. By considering each point in succession between the two drains it will be seen that there would be varying amounts of pressure needed to force the lower water into the tile. This pressure would vary from nearly zero at the tile to a maximum at a point about midway between the tile. The heights of "stack water" needed to produce this pressure would vary from a minimum at the tile to a maximum height at the midway point. A line joining the tops of successive "stacks" would, then, form a curve which is known as the *ground-water curve* or *plane of saturation*.

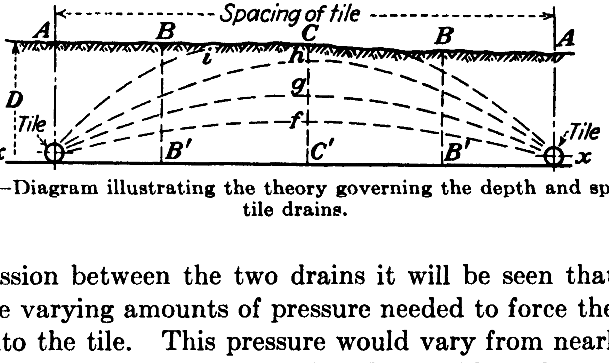

FIG. 269.—Diagram illustrating the theory governing the depth and spacing of tile drains.

If the tile is placed in a sandy soil, the water can work through it easily; consequently, not much pressure is needed to force the water into the tile, and the curve takes a flat shape, such as curve *f*. Should the soil be a sandy loam, the pressure required would be greater, and it would take a shape such as curve *g*. In a clay loam, the curve would be sharper and would take the shape of *h*, while in a heavy clay it might come to the surface in the center and take the shape of *i*.

From the foregoing discussion the following conclusions can be drawn regarding the proper *spacing and depth* of tile drains:

In an open soil, such as a sandy soil, the tile can be placed far apart, because the plane of saturation is a flat curve and will not come near the surface except in extreme distances.

In a tight soil, such as a stiff clay, the tile should be placed close together, because the plane of saturation is a sharp curve.

Intermediate types of soil should be judged accordingly. In regard to depth of tile in open soils, the tile should be deeper than in dense soils, because water works through more quickly. *The closer together the tile the shallower they should be; the farther apart the deeper they should go.*

451. Spacing for Tile Drains.—C. G. Elliott[1] gives the following for spacing tile drains:

> In close, dense soils, largely clay, 30 to 40 feet; coastal plain lands composed of mixed clays with fine sand and uniform structure, 60 feet; alluvial gumbo or heavy soils, but with granular structures, 70 to 80 feet, alluvial, glacial drift and sandy loam soils, with clay subsoils, 100 feet; sandy lands and soils containing considerable quantities of vegetable matter and those without subsoils having a liberal supply of sandy or gravelly material, 150 to 200 feet.

Tile have been placed as close together as 20 feet in gardens of a clay nature. In sandy soils, they are sometimes placed 200 feet, hardly ever over that, except in irrigated regions.

452. Depth of the Drains.—The depth of tile laterals varies from 18 inches to 4 feet. It is never desirable to place tile less than 18 inches in the ground because of the danger of plowing them up. The depth of a tile refers always to the distance the bottom of the ditch is below the surface of the ground. So a 4-inch tile placed 18 inches in the ground has its top only a little more than 12 inches below the surface. There are cases, in extremely flat ground, where it is necessary to "dig for fall," which may compel one end of the line of tile to be very shallow.

Tile placed in dense soils are often only 2 or 2½ feet, while in sandy soils, they are placed 4 feet. The tendency in the Middle West is to place tile drains deeper than formerly. Some years ago, 3 feet was considered a good depth in that country, but today an average depth of 4 feet is considered best. A rule of thumb sometimes heard is that a tile line will "draw" 1 foot on either side for each inch of depth.

In no case should the tile be placed below the surface of a layer of hardpan or other impervious material.

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[1] **Elliott, C. G., "Engineering for Land Drainage."**

453. Grade for Tile Drains.—The proper grade or fall for tile is the greatest obtainable. The idea that a tile can have too much fall is wrong. The minimum grade is absolutely flat. Tile, where it was necessary, have been laid flat, and the land has been drained, but this is to be advocated only in extreme cases. To install a line of tile with a flat grade requires much time and labor, as it must be absolutely level, for if a little downgrade is made in the tile, a corresponding upgrade must be made, and water will not run uphill without pressure.

A fall of $\frac{1}{10}$ foot per 100 feet is as flat as tile should, as a general rule, be placed, and it will be found difficult to maintain even this grade. A fall of $\frac{3}{10}$ per 100 feet is a nice grade to work to, and, of course, for falls greater than this, the tile is correspondingly easier to install. These larger falls are not so desirable that it is necessary to go to considerable trouble (such as digging for grade) and expense to get them. By *digging for grade* is meant placing the tile shallow at the upper end and deeper at the lower end, thus getting the fall by deepening the ditch. Another point should be remembered with reference to fall—the greater the fall the greater the carrying capacity of the tile.

Where the laterals enter the mains or submains, and where the submains enter the mains, it is best to increase the grade, if possible. This is done to eliminate the possibility of sediment being deposited at these points. The usual way of doing it is to make a drop at these points. That is, drop the water from the laterals into the main ditch as much as the diameter of the tile, if possible. See Chap. XXVIII for installation details.

To change water from a high velocity to a lower velocity by a change in grade is a bad thing, because of the danger of the tile filling with sediment. Where the grades are high and only a small change is made, no danger need be expected, but a change to a relatively flat grade is to be avoided if possible.

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CHAPTER XXVI

DESIGN OF TILE DRAINS

The design of a tile-drainage system involves a knowledge of the hydraulic principles governing flow in underground conduits, estimation of the run-off to be taken care of and selection of the proper tile capacity to fit, a decision regarding the most suitable depth and spacing of laterals, and the arrangement of the drains into systems that will best suit the ground and economically provide thorough drainage. Economical locating systems for tile and the most suitable depth and spacing of laterals for various soil types have already been discussed, and the other design factors will now be taken up in the order named.

454. Flow of Water in Tile Drains.—The laws governing flow of water in pipes have long been the subject of research by investigators of many nations, with the result that scientific knowledge concerning them is quite well advanced. Their application to the special case of flow in tile drains, however, is attended by certain distinctions that should always be kept in mind. The main characteristic that distinguishes tile drains from other conduits is the fact that water enters at every joint all along the line (for small tile at 1-foot intervals). To be conservative and practical, tile are always considered as flowing full (the maximum discharge occurs when flow depth is about 95 per cent of the diameter) under the motivating force of gravity, and the velocity of flow is taken to be the average of the rate of movement of all the filaments within the tile. Actually, this velocity is not constant but varies from a maximum near the center of the tile to a minimum at the circumference and diverges from a motion of pure translation by the formation of cross-currents and eddies, which occur at protruding edges and at other obstructions. In this respect, however, flow formulæ are no different from other engineering formulæ that are based on theoretical assumptions, and, when modified by the introduction of an empirical coefficient, determinable by test, the error resulting from their use becomes negligible.

455. Factors Governing Discharge.—Of the factors governing the discharge from a given drain, the following three are the most important: (1) the *slope* on which the tile is laid, or effective head; this is sometimes spoken of as the *grade* or *gradient;* (2) the *resistance* or "skin friction" developed by the water in sliding against the tile walls; this is expressed by an empirical coefficient; and (3) the *shape* of a cross-section through the drain, which is a measure of its hydraulic efficiency and, for drain tile, is always assumed to be circular. The effect of shape is expressed by the term *hydraulic radius,* which is the ratio of cross-sectional area to wetted perimeter. By *wetted perimeter* is meant the length of the line of contact between the water and the channel through which it is flowing; for tile flowing full, it is equal to the circumference.

456. Velocity Formulæ.—Several formulæ are in common use among drainage engineers for computing the velocity of water flowing in tile drains, and each one has its enthusiastic advocates, notwithstanding the fact that all such formulæ were originally developed for continuous and uninterrupted flow. It has been necessary to modify them materially to make them fit drain-tile conditions.

In 1920, however, Yarnell and Woodward,[1] after a number of experiments extending over several years, in a government laboratory at Arlington, Va., proposed a formula which is especially adapted to give the velocity of flow in drain tile. It is[2]

$$V = 138R^{2/3}S^{1/2}$$

Where V = the mean velocity in feet per second
S = the hydraulic grade or slope
R = the mean hydraulic radius
$S = h/l$ or fall in feet per foot expressed as a decimal fraction
h = the fall in feet between the points considered
l = the length in feet between the points considered
$R = a/p$
a = the area of tile opening or cross-section in square feet
p = the wetted perimeter or circumference of the tile in feet.

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[1] *U. S. Dept. Agr. Bull.* 854.

[2] This is the same as Manning's formula with a value of n approximately 0.011.

When V is found, then substitute in the following formula:

$$Q = aV$$

Q = discharge of tile in cubic feet per second
a = area of tile opening in square feet

When Q is determined, then substitute in the following formula:

$$A = \frac{Q}{Z}$$

A = the area in acres drained by tile
Z = the rate of run-off expressed as a decimal fraction (see Chap. XIII)

457. Size of Tile Chart.—The solution of the Yarnell-Woodward formula can best be accomplished by the use of logarithms,[1] but, with the assistance of a graph such as the one shown in Fig. 270, it is not necessary to perform any arithmetical computations in order to solve it. This chart has been prepared by computing the discharge for the various sizes of tile, on different grades, and then plotting the results on a logarithmic base. The diagonal lines marked with the size or diameter of tile represent the capacity of the tile when flowing full. The velocity of flow is indicated by the broken diagonal lines running approximately at right angles to the tile-capacity lines. The numerals across the bottom of the graph represent the slope or fall in feet per 100 feet, and those across the top show the same values in inches per 100 feet.

458. How to Use Chart.—To find the capacity of any tile line from 4 to 48 inches, follow up (or down, if expressed in inches) the vertical line representing its slope in feet per 100 feet until it intersects the diagonal line for the size of tile being considered. From this intersection, trace a horizontal line to the *left* and read the discharge in cubic feet per second from the scale at the left edge of the graph. A horizontal line extended from the point of intersection toward the *right* will show the number of acres that this particular tile will drain, with any drainage coefficient from ¼ to 1 inch.

To make this operation clear, assume a 12-inch tile, laid on a grade of 0.20 foot per 100 feet (nearly 2½ inches per 100 feet). It is desired to determine how many acres this main will serve if the proper drainage coefficient is ⅜ inch. Follow up the

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[1] Or the tables in the appendix giving two-thirds powers of R and one-half powers of S (square roots) may be used.

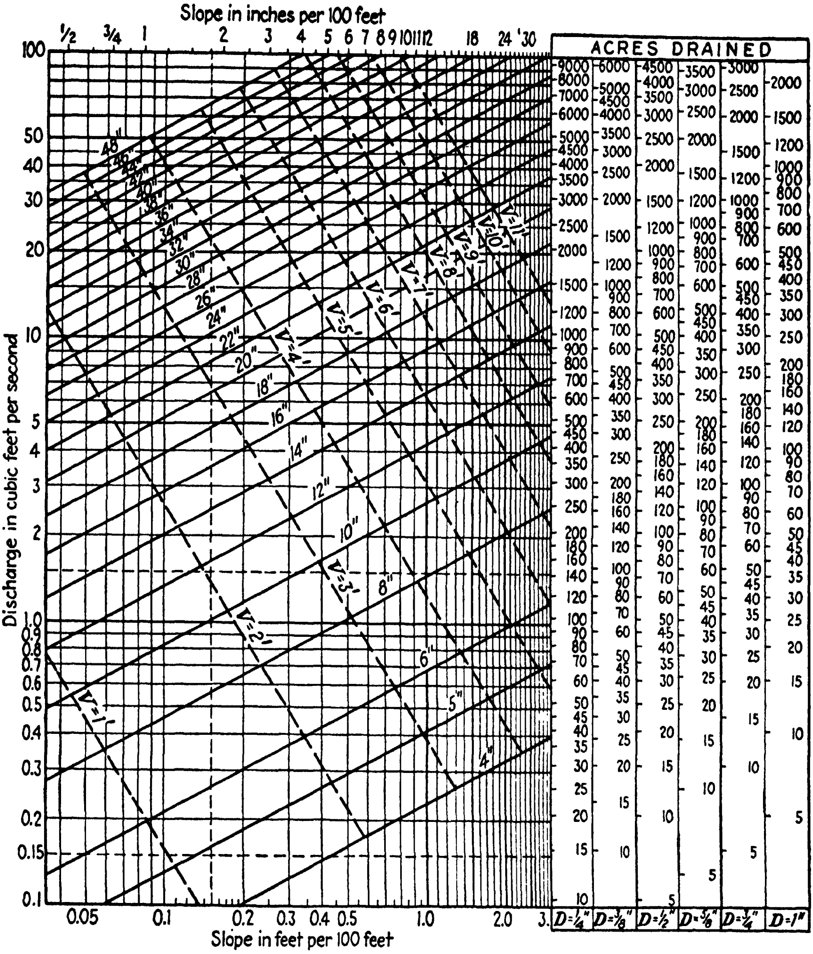


FIG. 270.—Discharge curves for drain tile. Based on formula $V = 138R^{2/3}S^{1/2}$ D = drainage coefficient. (*U. S. Dept. Agr. Bull.* 854.)

vertical line representing a slope of 0.20 foot per 100 feet until it intersects the diagonal line marked 12 inches, and then follow a horizontal line to the scale at the left, where it is found that this tile has a discharge capacity of 1.9 cubic feet per second. By following the same horizontal line to the right side of the diagram, it is found in the column over "*D* (run-off) = 3/8 inch" that this drain would take care of the discharge from 120 acres. If the drainage coefficient were 1/4 inch, this same tile would drain an area of 180 acres. The velocity of flow in the tile, as read from the diagram, would be nearly 2.5 feet per second.

It is thus seen that this diagram saves a large amount of work in making laborious calculations, and its use gives results that are accurate enough for all practical purposes. In practice, the problem is generally presented the other way around, for it is usually desired to know what size of tile is necessary to drain a given area with the slope or fall shown on the profile for that drain. After selecting the proper drainage coefficient, a horizontal line (real or imaginary) is drawn from the number of acres to be drained on the right scale toward the left until it intersects the vertical line representing the slope in feet per 100 feet. The size of tile, as represented by the diagonal line next above the point of intersection, is the proper size to use.

459. Selection of Drainage Coefficient for Tile.—The amount of water to take off each 24 hours in drain tile depends more upon the rainfall than upon any other one factor. The character of the soil, whether open or dense, as well as other factors of run-off, has considerable to do with it but not so much as rainfall. If only this one factor were taken into account, the following statement, consistent with current practice, may be accepted as a rough guide: 1/4 to 5/16 inch for regions with an annual rainfall less than 30 inches; 5/16 to 3/8 inch for regions with annual rainfall between 30 and 40 inches; 3/8 to 1/2 inch for regions with annual rainfall between 40 and 50 inches; 1/2 to 1 inch for areas with rainfall between 50 and 60 inches; and 1 inch or more for areas where the average annual rainfall is greater than 60 inches. Reference to the rainfall data will show that a drainage coefficient of 1/4 to 5/16 inch would apply to areas such as Minnesota, South Dakota, Nebraska, Kansas, and western portions of Oklahoma and Texas; 5/16 to 3/8 inch to Ohio, Michigan, Indiana, Illinois, Wisconsin, Iowa, Missouri, and the eastern portions of Kansas, Oklahoma, and Texas; 3/8 to 1/2 inch to Arkansas, Kentucky, southern Missouri, Tennessee, Maryland, Virginia, West Virginia, the Carolinas, Georgia, and the northwestern corner of Mississippi; ½ to 1 inch to Louisiana, Arkansas, Mississippi, Alabama, and Florida; 1 inch or more to the extreme southern portions of Louisiana, Mississippi, and Alabama, to the most easterly tip of Florida, and to Pacific Coast areas lying north of the 39th parallel of latitude. Where tile take surface water directly through inlets, these coefficients should be materially increased. How much can be determined only by experience; it is better to have the tile too large than too small. Some engineers make a practice of doubling the normal coefficient if inlets are installed.

460. Size of Laterals.—The size of laterals for tile drains should be figured only where they are extremely long. *Never use a smaller tile than* 4 *inch for laterals.* Three-inch tile, and often even two-inch, has been used for this purpose, but the practice is being discontinued, because these small tile have a tendency to fill up with silt, thus rendering it necessary to take them up. In many places, nothing smaller than a 5-inch tile is being used.

When laterals get over 500 feet long, their capacity should be figured and it should be determined if they are large enough.

461. Size of Mains and Submains.—The size of mains and submains should be computed by determining the area that they drain. Never take the combined capacities of the tile which empty their waters into the main to determine the size of the main. It can readily be seen that this method would give a tile too large and thus cause needless expense.

462. Sample Drainage Report.—The following report of a system of drainage worked out for a farm is given with the accompanying map to show what such a report should contain:

DRAINAGE REPORT FOR AUBURN PLACE (SEE FIG. 271)

Introduction

By arrangement with the owner, ————, drainage engineer of ————, visited a farm of ————, known as Auburn Place, for the purpose of making surveys and collecting such other data as might be necessary to plan a comprehensive system of tile drains. The farm in question is located in the south-west corner of Calhoun county, Iowa, and is described as a portion of sections 30 and 31, township 86 north; range 24 west. It contains approximately 387 acres.

Topography and Soil

Situated as it is in the heart of the Wisconsin drift area which stretches across 17 counties in north central Iowa, the topography of this tract is made up of a series of undulating ridges and flat depressions which have no natural drainage outlet.

The soil consists of a black sandy loam, tight and waxy in spots, underlain by a light-colored clay sub-soil mixed with considerable sand, gravel, and small boulders. This soil is of a type that responds quite readily to the action of underdrains.

Existing Drainage Conditions

In making a study of existing drainage conditions, the matter of outlet facilities came up for first consideration. It was found that wherever an outlet was needed, it had been provided—either by a county drain or by the termination of a property line on a steep hill. In fact, a drainage assessment of nearly $2,000 stands against this property as its share of the construction expense of the outlet drains. Notwithstanding this fact, nothing has been done to make use of the outlets by constructing the tributary laterals so necessary for thorough field drainage. As a consequence, a large portion of the farm remains in its original state of open ponds and native slough grass.

Cultivated fields are cut up by numerous tracts too wet to sustain any growth of crops. These wet spots of irregular outline thus become a double liability in reducing the area of production and in yielding no return on the labor of planting and cultivation.

Catch Basins

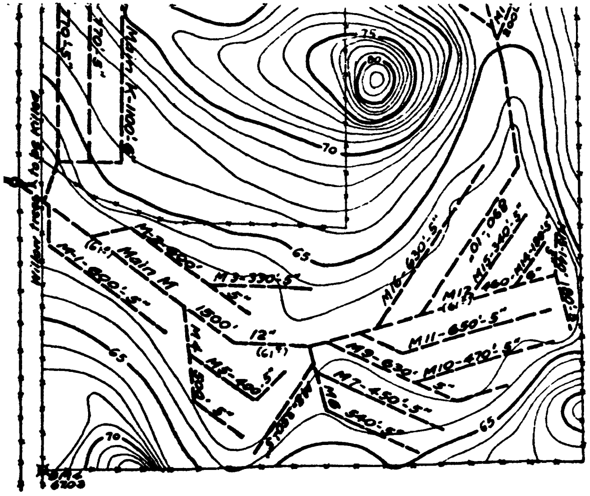
Four intakes or catchbasins for the ready accomodation of surface water have been constructed by the county and were inspected. Only one of these was found in good condition, the other three having been stopped up by débris or else washed out and undermined by floods. The repair of these inlets is a matter of serious concern and should be brought to the attention of the county supervisors without delay.

Stoppage by Roots

In some places, roots from willow trees have entered the tile and practically destroyed its capacity to carry water. Here the tile must be dug up, cleaned, and relaid, and the trees killed before installing any tributary drains. No tile closer than 125 feet to such a tree is safe from willow roots.

The Drainage Plan

A map has been prepared showing the usual topographic features with contours at intervals of 1 foot. The proposed lateral drains appear in bold relief, and each line has been inscribed with its name, length, and size of tile. The arrangement indicated has been worked out after a very careful study of the entire situation, and it is believed that they represent the most effective as well as the most economical system that



Headwall at Outlets
25 ft. vit. Sewer P.

C-5	0-4+70	0.2	4.6	470	5"
C-6	0-2+45	0.3	4.0	245	6"
"	2+45-6	0.3	4.0	355	5"
"	6-7+40	1.0	3.6	140	5"
C-6-1	0-2+90	0.4	4.2	290	5"
C-6-2	0-1	1.5	3.6	100	5"
C-6-3	0-1	0.4	3.0	100	5"
D-1	0-4	1.7	3.5	400	5"
"	4-5	4.0	3.6	100	5"
"	5-7	0.8	4.1	200	5"
D-1-1	0-3+50	0.4	3.6	350	5"
D-2	0-5+90	0.4	4.6	590	5"
D-3	0-6	0.2	3.9	600	6"
"	6-12+40	0.6	4.2	640	5"
D-4	0-9+50	0.4	4.0	950	5"
D-5	0-4	0.2	3.6	400	6"
"	4-13	0.4	4.0	900	5"
D-6	0-5	0.2	3.7	500	6"
"	5-14+80	0.33	3.8	980	5"
D-7	0-5	0.2	3.9	500	6"
"	5-12+50	0.38	3.9	750	5"
D-8	0-15	0.2	3.6	1500	6"
D-9	0-15+50	0.2	3.6	1550	6"
D-10	0-14+50	0.2	3.8	1450	6"
D-11	0-14	0.2	3.7	1400	6"
D-12	0-2+50	0.2	3.7	250	5"
D-13	0-2+50	0.3	4.6	250	5"
MAIN E	0-4	0.45	3.7	400	6"
"	4-10	0.45	3.9	600	5"
"	10-13+80	2.80	4.1	380	5"
E-1	0-1+80	0.5	4.2	180	5"
E-2	0-3	0.6	4.4	300	5"
E-3	0-2	0.3	3.8	200	5"
"	2-3+50	0.5	4.0	150	5"
E-4	0-4+60	0.4	4.4	460	5"
E-5	0-4+30	0.2	3.6	430	5"
E-6	0-2+70	0.3	4.3	270	5"
E-7	0-3+70	0.3	4.0	370	5"
E-8	0-3	0.3	3.7	300	5"
E-9	0-1	0.4	3.7	100	5"
MAIN F	0-5+65	1.3	3.7	565	6"
F-1	0-4+60	0.3	3.9	460	5"
F-2	0-4+60	0.2	3.7	460	5"
K-2	0-4+50	0.2	3.3	450	5"
K-3	0-3+60	0.2	3.7	360	5"
K-4	0-7+70	0.5	4.1	770	5"
K-5	0-7+70	0.73	4.0	770	5"
MAIN M	0-15	0.1	2.9	1500	12"
"	15-23+90	0.1	3.2	890	10"
"	23+90-34+65	0.23	4.7	1075	8"
"	34+65-44+40	0.23	4.6	975	6"
M-1	0-6	0.15	3.6	600	5"
M-2	0-6	0.2	3.8	600	5"
M-3	0-3+30	0.2	3.2	330	5"
M-4	0-5	0.15	3.2	500	5"
M-5	0-4	0.1	3.2	400	5"
M-6	0-5+40	0.4	3.6	540	5"
M-7	0-4+50	0.5	3.5	450	5"
M-8	0-3+50	0.2	3.1	350	5"
M-9	0-6+30	0.1	3.2	630	5"
M-10	0-2+50	0.1	2.5	260	5"
"	2+30-4+70	0.3	3.3	220	5"
M-11	0-6+50	0.1	2.0	650	5"
M-12	0-4+60	0.1	2.0	460	6"
"	4+60-6+40	0.1	2.4	180	5"
M-13	0-1+40	0.1	2.8	140	5"
M-14	0-1+80	0.1	2.3	180	5"
M-15	0-3+40	0.1	2.7	340	5"
M-16	0-6+30	0.2	3.2	630	5"
M-17	0-2	0.5	4.1	200	5"
M-18	0-3	0.3	3.9	300	5"
M-19	0-5	0.2	4.4	500	5"
M-20	0-4+40	0.2	3.6	440	5"
M-21	0-3+60	0.2	3.5	360	5"
M-22	0-2+60	0.2	3.6	260	5"
M-23	0-2+50	0.4	4.0	250	5"
M-24	0-5	0.3	4.4	500	5"
M-25	0-4+40	0.3	4.1	440	5"
M-26	0-3+90	0.2	3.3	390	5"
M-27	0-2+60	0.2	4.0	260	5"
M-28	0-2+50	0.2	3.8	250	5"
M-29	0-2+30	0.2	3.3	230	5"
M-30	0-2+40	0.2	3.8	240	5"
M-31	0-2+20	0.2	3.2	220	5"

—Drainage map of the Auburn Place. Typical layout of tile drains for thorough drainage of a 380-acre farm with gently rolling topography.

can be devised. Nothing less than all the drains shown will yield maximum return for each dollar invested and provide adequate drainage for every square foot of the farm.

Piecemeal Construction

It is recommended that all the drains be installed under one contract for best results, but, if other considerations make this impracticable, piecemeal construction will afford some relief. It is important to keep the general plan always in mind and plan each season's work so that eventually the systems as shown will be complete. In selecting the drains for immediate installation, preference should be given those that skirt the foot of slopes and thus intercept the hill water before it has a chance to saturate the flat land below.

Special Problems

The outlets for systems *A* and *B*, on the north fence line, will be into steep draws leading to another county drain farther north. Substantial walls should be built to protect the last few pieces of tile, and for 25 feet back from the outlets vitrified sewer pipe should be used to guard against damage by frost.

The drains of systems *A*, *B*, and *C* could be made to operate most efficiently in conjunction with a series of terraces as outlets for the water thus retarded. Some of the slopes in this region are as steep as 5 feet per 100, which is sure to cause trouble from washing sooner or later. It is at least extremely unwise to continue the present practice of plowing rows directly down the slope, thereby inviting excessive acceleration of surface water with consequent high velocities and erosive action. With the exercise of a little more care, rows can be run across the slope and be made to obstruct the direct descent of water and force it to wind slowly back and forth.

Surface Inlets

Three "holes" were found directly over the 10-inch county tile serving system *D*, testifying to the inrush of water to a crevice in the drain. To cure this condition, inlets should be installed at the points shown on the map. For 10 feet above and below the inlets, the joints of the tile should be wiped with cement, and a concrete collar should be built around the top of the inlet after the filled-in earth has settled. This treatment will force the water to enter through the inlet and not wash down around the outside. All the inlets should be constructed on vertical junctions of 6-inch sewer pipe with cemented joints. The top should be covered with a "beehive" cast-iron grating.

Inlets will doubtless prove useful at other points than those indicated, but it is better to wait and see from experience where they are needed and then install them at the exact spots where they will be of most benefit.

All features of the other systems are thought to be self-evident from the map and profiles. It may be well to add, however, that the junctions should be formed by the use of regular junction or Y tile made for that purpose. Before system *J* can be installed, it will be necessary to drain off the surface water by an open ditch and then kill all the willow saplings and grub up the stumps. The 12-inch tile in system *M* is necessary on account of the flat grade on which it must be laid. Its capacity is less than that of the 10-inch tile, on a steeper grade, into which it empties.

This report is accompanied by one map and two sets of profiles.

ESTIMATE OF COST. TILE—F. O. B. AUBURN

Number of feet	Size, inches	Type	Cost, per 1,000 ft.	Total cost
25	8	Sewer pipe	$170.00	$ 4.25
25	6	Sewer pipe	120.00	3.00
1,500	12	Drain tile	205.60	308.40
890	10	Drain tile	161.00	143.20
2,170	8	Drain tile	87.50	189.87
16,825	6	Drain tile	56.50	950.61
36,210	5	Drain tile	45.40	1,643.93
				$3,243.26

Y JUNCTIONS

Number of Y junctions	Size, inches	Cost, each	Total cost
1	12 by 6	75 cents	$ 5.25
5	12 by 5		
1	12 by 10		
2	8 by 6	40 cents	5.20
11	8 by 5		
2	6 by 6	25 cents	9.75
37	6 by 5		
18	5 by 5	15 cents	2.70
			$22.90
		Total tile cost.	$3,266.16

Hauling and distributing in field:

2½ miles average haul @ 50 cents per ton mile, 280 tons by 2.5 by 0.50 .... $350.00

DIGGING, LAYING, AND BACKFILLING

Length of tile, feet	Size of tile, inches	Depth, feet	Cost per foot	Total cost
53,060	5 and 6	3 to 5	0.05	$2,653.00
2,195	8	3 to 5	0.06	131.70
890	10	3 to 5	0.07	62.30
1,500	12	3 to 5	0.08	120.00
				$2,967.00

Cleaning old tile (rough estimate)	$100.00
2 headwalls $15 each	30.00
3 inlets $10 each	30.00
	160.00
Total	6,743.16
Engineering and incidentals, 5 per cent	337.16
Grand Total	$7,080.32

Cost per acre, $7,080.32 ÷ 387 = $18.30

Problems

59. How many acres would a tile 8 inches in diameter, with a grade of 0.4 foot per 100 feet, drain if a drainage coefficient (*a*) of 1/4 inch were used? (*b*) of 3/16 inch? (*c*) of 9/16 inch?

60. Laterals are spaced 100 feet apart in the field; they have a fall of 0.3 foot per 100 feet; they are 1,500 feet long. Use drainage coefficient of 1/2 inch. What size tile would you use for laterals?

61. How many acres will a 15-inch tile drain with a fall of 0.14 foot per 100 feet drain with a drainage coefficient of 1/2 inch?

62. How many acres will a 38-inch tile drain with a fall of 0.3 foot per 100 feet with a drainage coefficient of 1/2 inch. How many square miles?

63. How many acres would the tile in Example 62 drain if a drainage coefficient of 3/8 inch were used?

CHAPTER XXVII

SELECTION OF TILE

463. Essentials of a Good Drain Tile.—Good drain tile, to be used for agricultural purposes, must be regular, dense, strong, and sound. These qualities are assured by specifying that all tile purchased shall meet the standard specifications of the American Society for Testing Materials; the specifications can be obtained in pamphlet form by addressing the Secretary of the Society at Philadelphia, Pa. They carry requirements for three classes of tile—farm drain tile, standard drain tile, and extra-quality drain tile, depending upon the purpose for which the tile are to be used. For practically all private farm drainage work, farm drain tile are satisfactory and should be specified.

The tests to be performed are described in minute detail in this pamphlet, but they are impracticable for most purchasers. The purpose of the following discussion is to give rough rules for tests that are easily performed and give a good indication of the quality of tile.

464. Regular Tile.—By a drain tile being *regular* is meant that it is round with the ends clean-cut. A tile which is oval or out of round and thus not true is hard to lay to grade in a ditch. A tile with ragged ends is difficult to lay up against the end of the tile next to it. Tile which are not regular will cause unnecessary labor in installing and are apt to be unsound.

The maximum allowable variations recommended by the American Society for Testing Materials for farm drain tile are as follows:

Allowable variation of average diameter below specified diameter, per cent	5
Allowable variation between maximum and minimum diameters of same tile, or average diameters of adjoining tile, percentage of thickness of wall	85
Allowable variation from straightness, per cent of length	5

465. Dense Tile.—The amount of water that a dry tile will absorb is an indication of its strength. As a rule, tile which absorb large quantities of water are weaker than those that absorb small quantities. The denser a tile is the lower absorption it will have and, hence, the stronger it will be.

The Iowa State College Engineering Experiment Station, after making extensive experiments along this line, makes the following recommendations regarding the allowable absorption of tile:

For farm tile made of concrete:	
Allowable absorption, per cent	8 to 11
For farm tile made of clay:	
Allowable absorption, per cent	8 to 16
For large tile drains made of concrete:	
Allowable absorption, per cent	6.5 to 9
For large tile drains made of clay:	
Allowable absorption, per cent	6 to 7

This absorption test can be made by first drying the tile and weighing it, then placing it in water for 24 hours, again weighing, and then computing the per cent gain in weight.

Tile made of certain kinds of glaciated clay have the peculiar property of being strong and satisfactory, despite a high percentage of absorption. If the absorption is much higher than that allowed, a "freezing-and-thawing" test is made, and if the tile endures this without serious disintegration, it is considered acceptable, provided it passes all the other tests. In the great majority of cases, however, this question should never come up.

The idea has long been prevalent that a good tile should be capable of absorbing large quantities of water in order to insure that the water gets into the tile. The fact is that very little water gets into the tile by soaking through the walls, even when the former is very porous. The vast majority of the water enters the tile through the joints. The reason for this is obvious when the question is considered. No matter how carefully the tile are placed in the ditch, they cannot be laid up so absolutely close together that no water can enter. In fact, in most cases, there will be at least a $\frac{1}{16}$-inch opening between the tile, and in many cases it will be larger. Consider, now, whether water in the soil will work itself through the walls of a tile or go through the joints. It will, of course, take the path of least resistance. Hence, no matter how porous a tile is, that fact will not materially help its draining qualities, nor does it appear possible for water to soak through the tile. Experiments have been made which bear this out.[1]

An experiment was made by Drainage Investigations, U. S. Department of Agriculture in 1910, which illustrates the property fairly well. Two 6-inch and two 3-inch drain tile made out of common brick clay, burned a salmon color, and as soft as are usually considered safe to use, were sealed at one end with cement mortar. They were immersed in water until they became saturated and afterward placed in a tank of water in which the surface was kept within ¼ inch of the top of the tiles. The tiles were covered so as to prevent any loss of water which percolated through the walls. The depth of water which accumulated in each of the tiles was measured at the end of 4, 24, and 48, and 72 hours, and the volume in cubic feet and gallons computed. The experiment was then reversed, the tile being filled with water, and the amount which percolated through the walls collected in a saucer and measured. During this part of the experiment, the tiles were placed in a damp closet so that no water would be lost by evaporation. The results were as follows: Taking the average of the measurements, the four tiles showed a percolation of about 0.0049 cubic feet per square foot of surface in 24 hours. If 1 acre of ground were drained with lines of 6-inch tile of this quality, placed 50 feet apart, the total volume of water which would pass through the walls in 24 hours would be 6.92 cubic feet or 51.7 gallons. This is on the assumption that free water instead of saturated soil would surround the tile. *If water entered only through the pores it would require* 139 *days to remove ¼ inch in depth of water from the acre, tiled in this manner, and* 250 *days if* 3*-inch tile of the kind experimented with, were used.* But drains so laid are capable of removing that volume of water from the soil in 24 hours.

It can be seen from this experiment that it would be absolutely impossible for tile to do the work if it had to depend upon the water's soaking through the walls.

Manufacturers have been known to use as a selling point the fact that their tile would absorb large quantities of water and represent it to the prospective buyer by pouring a glass of water on a tile (all the water soaking in). This should, however, be considered a defect rather than a recommendation.

Absorption has another harmful action. In cases where soils contain alkali or other foreign materials, the absorption of these deteriorating agents causes the tile to weaken and finally collapse. The denser a drain tile is, therefore, the more desirable it is. Also, a dense structure is desirable where tile are exposed to cold air in winter, as below surface inlets, because the less water they absorb the less they are injured by freezing and thawing. Porous tile quickly go to pieces in Northern climates when stored in the open during the winter months.

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[1] ELLIOT: "Engineering for Land Drainage."

466. Strength and Soundness.—The need of a strong tile for drainage is due to the heavy load placed on it by the earth fill in the trench. Many tile have collapsed under this load (see Fig. 272), and, of course, whenever this happens, the tile system is useless until the broken tile is taken up and replaced with a good one.

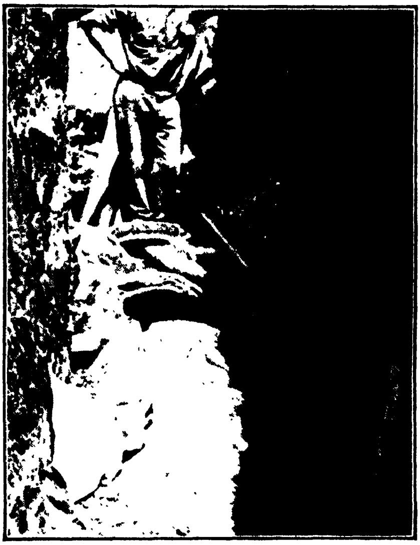

FIG. 272.- Tile of insufficient strength that are placed too deep will break down.

Farm drain tile, up to 12 inches in diameter, should have sufficient thickness of wall to enable them to withstand a load of from 600 to 800 pounds per foot of length. Generally, if small tile will support the somewhat concentrated load of a heavy man without cracking, they are satisfactory. Most tile that stand rough handling in loading and shipping by rail, without showing signs of distress, are strong and tough enough to give good service.

Extensive investigations have been made along this line recently, and it has been found that, in ordinary work, for sizes up to 10 inches in diameter, drain tile can be hardly put in deep enough to cause a failure—that is, provided that a good substantial tile is used. Above 10 inches in size of tile, if used lower than 5 or 6 feet, the tile should be tested and computations made to determine the load to which it will be subjected.

Tile should be sound, that is, free from cracks, chips, soft spots, blisters, and all other imperfections. Common tile which are overburned are likely to develop these defects and become brittle like glass. One weak tile, once in the ground, will endanger the long life of a whole system.

In this connection, the recommendations of the American Society for Testing Materials are as follows:

Allowable thickness of exterior blisters, lumps, and flakes which do not weaken tile and are few in number, percentage of wall thickness	25
Allowable diameter of above blisters, lumps, and flakes, percentage of internal diameter of tile	20

467. Kinds of Tile.—Drain tile are made of two different materials—clay and concrete.

468. Clay Tile.—Clay tile used for agricultural purposes are of two kinds—common and vitrified.

The common tile is the one most used and is made of the same kind of clay and burned the same as common brick. This kind of tile is used more than any other for drainage. It should be burned until it is good and hard. The usual test is to hit it with a steel trowel. If a good sharp ring results, the tile is of good quality. A much more satisfactory test would be to gage its absorption.

These tile, in diameters up to 10 or 12 inches, come in 1-foot lengths; above that, they are sometimes 18 inches or 2 feet long, while, for the very large tile, they often come in 3-foot lengths.

The vitrified tile is often glazed like a jug. Such tile are, as a rule, stronger than the common clay kind and have less absorption. "Seconds" of sewer pipe can often be obtained at prices reasonable enough to allow them to be used in their large sizes for drains on farm lands. Ordinarily, however, this form of tile is used for sewer work.

469. Concrete Tile.—Concrete tile are made of sand and cement, the usual proportion being 1 part cement to 3 or 4 parts sand. Leaner mixtures than this should not be allowed. Concrete for tile should be well mixed and tamped into the tile forms. The curing should also be well done. There are two methods of curing—water and steam. The water method is the natural one and consists of sprinkling the tile each day for at least 2 weeks. The tile should not be used for 30 days. Steam curing consists of placing the tile in a room filled with steam. Tile cured by this method are ready to use in 15 days.

470. Concrete vs. Clay Tile.—The question as to which is the better of the two tile—the concrete or the clay—depends for its answer on the particular concrete or clay tile to be chosen. Clay tile which is poorly molded and half burned is not to be considered and, if purchased, will represent only money thrown away. On the other hand, concrete tile made of a mixture too lean, poorly mixed, or poorly cured is in the same class. A well-burned and properly made clay tile is the equal of a well-made and properly cured concrete one. They are both very durable and will give about the same degree of satisfaction. If a first-class product of either one is compared with an inferior product of the other kind, the former should be selected.

If there is reason to believe, however, that the soil water is strongly alkaline,[1] it is well to have careful tests made of the water to determine the nature of the impurity and the quantity in which it is present. In such localities, the safest plan is to use only good clay tile, as the alkali attacks the cement and gradually disintegrates concrete tile. If this would be too expensive, the advice should be sought of a competent engineer who will know what precautions to take to insure that the tile will be reasonably durable. Exhaustive tests carried on by the U. S. Department of Agriculture cooperatively with the University of Minnesota seem to indicate that most of the trouble is caused by sulphates of sodium and magnesium. These seem to attack the cement and leach out by chemical action its calcium constituent, thus destroying the binding properties of the cement. Where the sulphate content of soil water is more than

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[1] D. G. Miller, U. S. drainage engineer, defines the meaning of the term "alkali," as follows: The meaning of the term "alkali," as generally accepted among English speaking workers in arid regions, refers to water soluble mineral salts more or less injurious to vegetation and has no relation to the same term as used by chemists. Chemically considered, a soil alkali is a water soluble mineral salt and may occur as a number of chemical compounds. Alkali most commonly occurs as sodium sulfate (Na_2SO_4), known medicinally as Glauber's salt; magnesium sulfate ($MgSO_4$), or Epsom salts; sodium chloride ($NaCl$), or salt; sodium carbonate (Na_2CO_3), or sal soda, and sodium bicarbonate ($NaHCO_3$), or baking soda. As found in the soil, alkali may be a mixture in almost any proportions of any two or more of these salts.

1,500 parts per 1,000,000, concrete tile should not be used unless they have been specially prepared to resist such action. Just what constitutes the best method of preparation for developing resisting qualities is still an open question, but exhaustive experiments, now underway, seem destined to solve the problem in the near future. Indications are that special methods of curing and the selection of certain brands of cement will have a great deal to do with the working out of a satisfactory solution.

The action of acids in peat soils is less well understood but is also receiving attention by research engineers.

Tile specials—Y's and T's—can usually be obtained from manufacturers of clay and concrete tile to make joints between two lines of tile. These specials are not expensive, and they assist in making a good job. They can be obtained not only for joining the same sizes of tile but also for joining a small lateral to a larger main or submain. Reducers are also obtainable for gradually changing the tile size at breaks in the grade and at other points.

CHAPTER XXVIII

INSTALLATION OF TILE

471. Methods of Establishing Grade.—There are four different methods used to get grades for laying tile. They are the water method, sighting method, line-and-gage method, and line-and-rod method.

472. Water Method.—This method consists of starting the ditch at the upper end, digging out a small section, and putting water in it. Then continuing to dig the ditch for the tile, so that the water will run in the ditch, the idea being that if water will run in the ditch it will run in the tile.

This method is rather crude in that it does not call for any survey or profile to be made. It can be used only where there is an abundance of fall and should not be used then, because the grade will not be uniform, and pockets in the line of tile will occur which are likely to fill with sediment.

473. Sighting Method.—This consists of setting up at each of the grade stakes a tall stake with a crossbar on it (Fig. 273). These crossbars have their upper edges just 5 feet above the bottom of the ditch, and this is accomplished by taking the cut or depth the ditch is to be dug at the station and subtracting it from 5 feet, thus obtaining the height that the upper edge of the crossbar should be above the stake. If the ditch has a cut of 3 feet at some station, then the crossbar should be 2 feet above the grade or hub stake at this point. A pole 5 feet long is then used by the "bottom man" who thus determines when the trench is

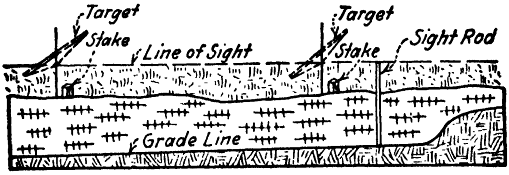


Fig. 273.—Sighting method. Set targets so that a line of sight over their upper edges will be parallel to the desired grade line.

cut to grade. To see if he has it to the required depth, he holds this pole with one end on the bottom of the ditch and sights over the upper end of it to see if it lines up with the cross bars.

This method is used to some extent, but the inability of the inexperienced laborer to sight true restricts its application to localities where veteran tilers are available.

474. Line-and-gage Method.—This method consists of placing tall stakes alongside of the grade or hub stakes and driving them down until the tops are just 5 feet above the bottom of the ditch (Fig. 274), as is done in the sighting method. Over the tops of these stakes a string or line is stretched. This line will show the grade of the bottom of the ditch, and it is just 5 feet above it. Next, a gage is made in the form of a capital L, upside down. This is made 5 feet from the bottom end to the lower side of the horizontal arm. The arm is 18 inches or 2 feet long. The grade of the bottom of the ditch is obtained by placing the end of the upright part of the gage on the ditch bottom, and noting whether the horizontal arm touches the string. When the underside of the arm does just touch the string, the ditch is on grade.

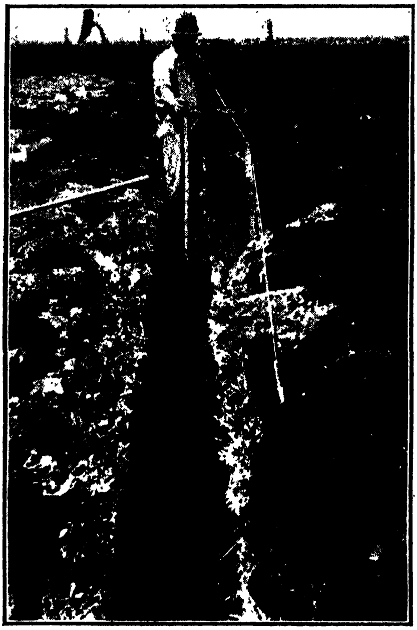


FIG. 274.—Testing the bottom for grade the "line and gage" method. (*Courtesy of Mason City Brick and Tile Company.*)

As this method is both simple and effective, it is the one most frequently used. Care should be taken to see that the gage is held vertical at the time of making the test. If the upright portion is not truly vertical, some error will result.

475. Line-and-rod Method.—The line-and-rod method consists of nailing a board across the ditch at each station 5 feet above the bottom of the ditch (Fig. 275). On the center of these boards, a string is attached which would be over the center of the ditch. A straight stick, 5 feet long, is used for a gage. The trouble with this method is that the line, being over the ditch, is in the way.

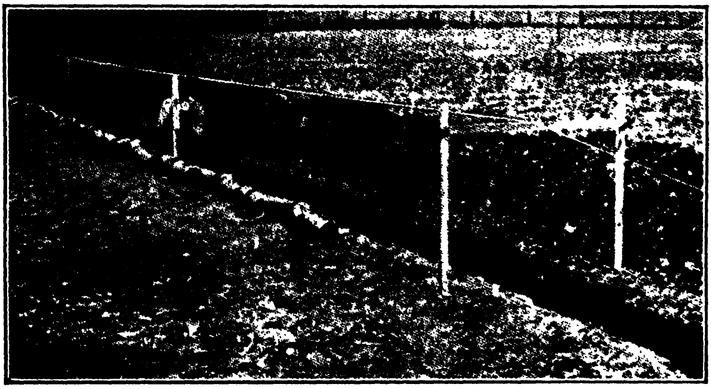


FIG. 275.—Testing grade by the use of the "line-and-rod" method.

476. Digging the Ditch.—There are two methods of digging trenches for tile—by the use of machines and digging with hand tools.

477. Machine Ditching.—There are two general types of machines on the market for digging ditches for tile—those having a revolving wheel (Fig. 276) or endless chain (Fig. 277), with attached buckets, and those which are various forms of plow ditchers. To be entirely satisfactory, any ditching machine must be capable of cutting true to grade, it must operate efficiently in any kind of soil, and it must be able to work for long periods of time without breaking or otherwise getting out of order.

The first-named type is made by several firms and they have done very satisfactory work where a large amount of ditching is to be done (more than 5,000 rods), where soil conditions are favorable, and where competent help is available to operate them. As a rule, however, it is not economical for the individual farmer to own such a machine unless his situation meets the requirements in the preceding sentence. It costs about $3,500 or more.

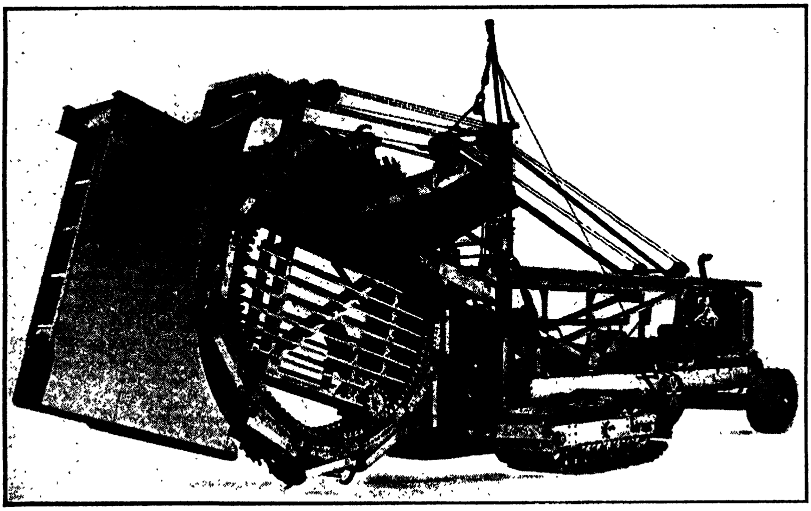


FIG. 276.—A late model of the wheel-and-bucket type trenching machine showing self-cleaning buckets and shield to prevent caving. (*Courtesy of Pawling and Harnischfeger Company.*)

The plow ditcher is a much cheaper piece of apparatus (Fig. 279). It is shaped like a large plow and acts much in the same way. This ditcher can not work to an accurate grade and it is used only where an abundance of fall is available. It has not been proved an unqualified success. The cost of such a plow is about $1,500. Other types of ditching plows are of lighter construction and are intended only to loosen the earth which is

FIG. 277.—A Parsons endless chain-and-bucket machine showing ladder lifted out of trench for inspection.

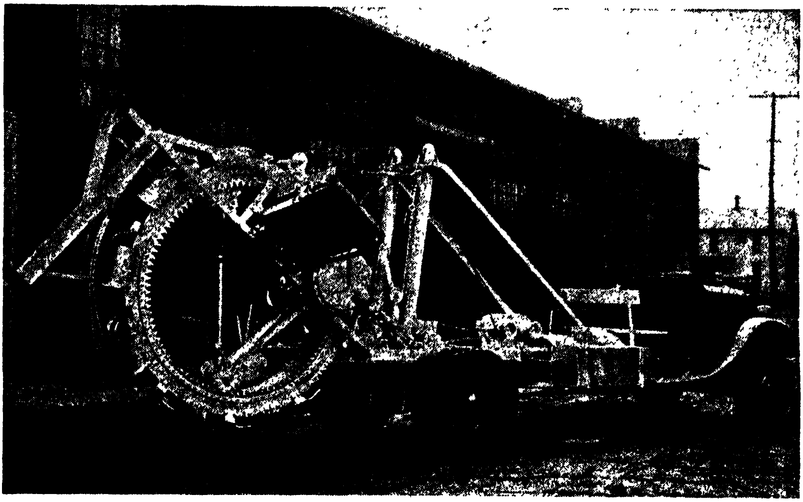


FIG. 278.—Modern portable ditching machine mounted on standard motor truck chassis. (*Courtesy of The Buckeye Traction Ditcher Co.*)

FIG. 279.—A "Cyclone" plow ditcher in operation.

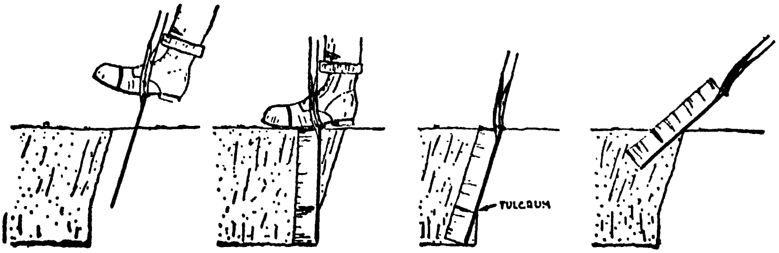


FIG. 280.—The effort required in hand digging is reduced by starting the cut with considerable slope and ending the cut vertically. The slice is pried loose over a fulcrum near the bottom of the trench.

then shoveled out by hand. These are also of very limited practical application.

478. Hand Ditching.—Hand ditching is by far the more common method, as it can easily be learned by inexperienced laborers.

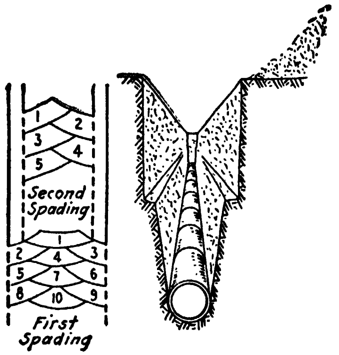


FIG. 281.—View showing each step in spading a shallow trench in the order that results in a minimum of labor.

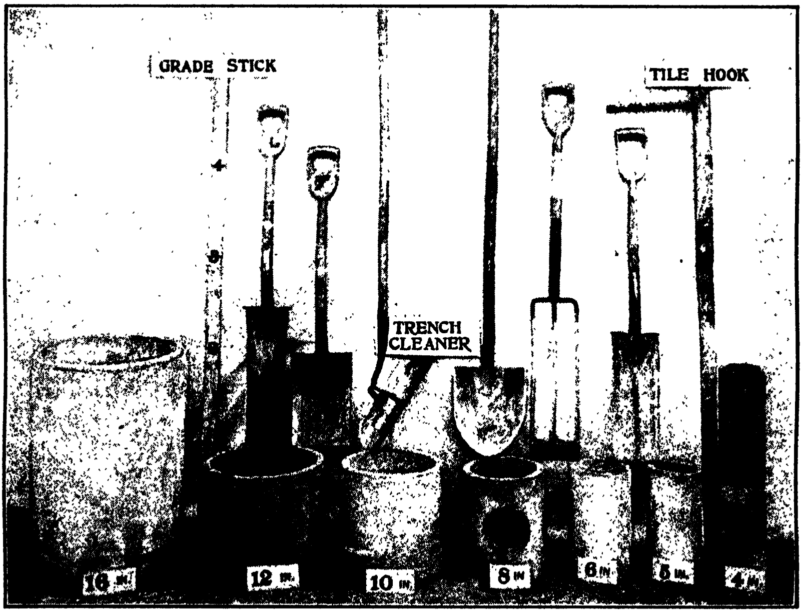


FIG. 282.—Samples of clay tile and ditching tools.

There is, however, in this form of ditching, a certain knack that can be acquired only by experience (Figs. 280 and 281).

Special forms of spades should be obtained and used for the work (Fig. 282). These spades are called *drain* or *tile spades* and can be obtained with the spade part solid or open and in lengths of from 14 to 20 inches. The open or skeleton spade seems to work best in wet, sticky ground, as it allows the water to run out and reduces the friction. Spades may also be obtained with square or round points—square for the top spading (Fig. 283) and round for the bottom layer. A trench for tile of 4 to 6 inches diameter, which are to be laid at ordinary depths, should be started only 12 inches wide at the ground surface, the object being to remove the smallest possible amount of dirt and save needless work. To the novice, this will seem rather narrow, but with a little experience it will be found to be wide enough.

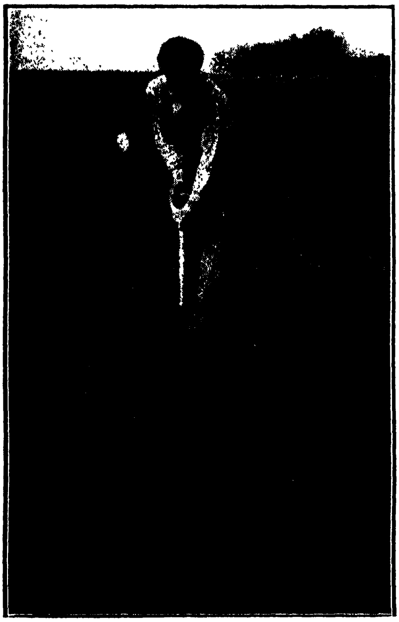


Fig. 283.—The first spading being executed true to line, note how the "topman" offsets the ditch from the hub stake. (*Courtesy of Mason City Brick and Tile Company.*)

Fig. 284.—Cleaning out or "crumbing" after the first spading. A good spader leaves few "crumbs." The soil within plow depth is placed on one side of the trench, subsoil on the other. (*Courtesy of Mason City Brick and Tile Company.*)

The loose earth in the bottom of the ditch should be taken out with a long-handled, round-pointed shovel (Fig. 284).

The last spading should not take the earth out lower than 2 or 3 inches above the grade line or bottom of the ditch (Fig.

285). The man taking out this last spading should be provided with a gage 2 or 3 inches shorter than 5 feet.

The last part of the ditch should be taken out with the *ditch cleaner*, or *scoop*, which shapes the bottom of the ditch so that the tile will fit (Fig. 286). The man using the cleaner or scoop should stand on the unfinished part of the ditch and draw the cleaner toward him.

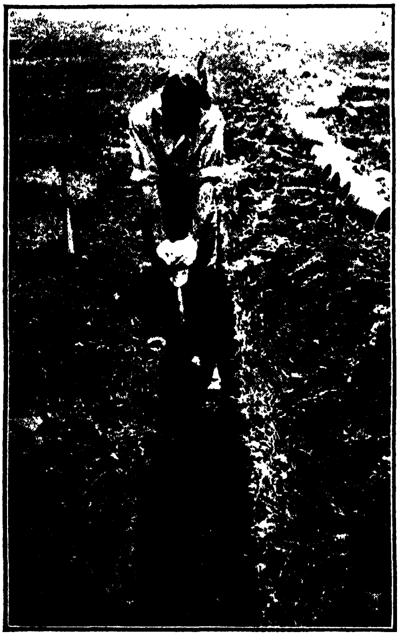


FIG. 285.—The second spading showing tile distributed along the ditch ready for laying. (*Courtesy of Mason City Brick and Tile Company.*)

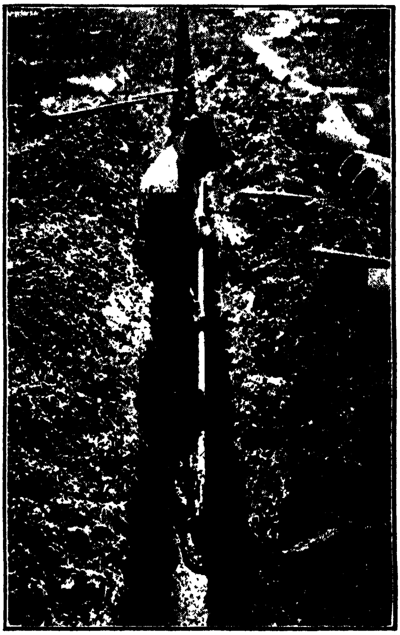


FIG. 286.—Dressing the trench bottom, true to grade with the tile scoop, making it ready to receive the tile. (*Courtesy of Mason City Brick and Tile Company.*)

479. Laying Tile.—For laying small tile, say up to 8 inches, a tile hook should be used (Fig. 287). This tile hook has a handle like a hoe, and on one end it has a $3/8$- or $1/2$-inch rod inserted, which projects a short distance and then turns a right angle. Tile hooks can usually be purchased at the local hardware stores. By using an ell, they can be made from $3/8$- to $1/2$-inch water pipe. Some farmers cut small limbs from trees which have a crotch of a sufficient angle.

The use of this hook is very simple. The tile layer stands astride the ditch. He inserts the hook into a tile and lowers it into the ditch. Then, by means of the hook, he turns the tile over and pushes it up close until it fits well against the next tile. The novice finds this method slow and tedious, but a little practice will enable him to place tile better and more quickly with this hook than any other way.

FIG. 287.—Illustrating the use of the tile hook in laying tile. (*Courtesy of Mason City Brick and Tile Company.*)

Some prefer to lie down on the ditch bank and place the tile by hand in the ditch. This method is wearisome and not so fast as the tile hook. Others prefer to get into the ditch. This should not be done with small-sized tile, because walking in a finished ditch spoils the shape of the bottom and walking on tile moves them out of place.

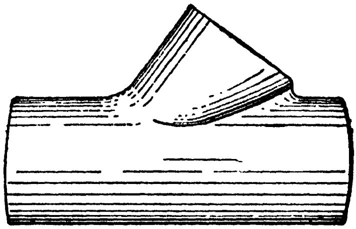


FIG. 288.—A factory-made junction.

In placing the tile, the layer should try to get them to lie as close together as possible. Some people think that a small space should be left for the water to get in. No matter how well they are fitted together, as a rule, there will be ample space for the water. Have the tile lie flat. Turn them over and over until they fit up close and true.

Broken ends of the tile should be placed on the bottom. All wide cracks should be covered with a broken piece of tile. In making curves, it is well to chip off one side of the tile in order to get them to fit closely, or else they may be laid close on the inside edge of the curve, and bats carefully placed over the wide cracks on the outside edge.

Joints between two lines of tile should be made with tile specials, if possible (see Fig. 288). If these are not available, a hole should be cut into one tile, and the joining tile chipped to fit up close (Fig. 289). Broken pieces of tile should be carefully fitted over the wide holes and cracks and should be held firmly in place with tough sod or concrete. Theoretically, it is better to begin the laying of the tile at the upper end, proceeding toward the outlet, as mud is not so likely to be washed into the tile if a rain should come before the line is finished. Practically, however, it is an almost universal custom to commence at the outlet of each line and work upstream. It very frequently happens that the tile must be laid through wet, saturated ground, in which case the work must necessarily begin at the outlet so that the surplus water can be disposed of. Each night, the upper end of an incomplete tile line should be securely plugged, and the tile should be blinded (backfilled) to a depth of 6 or 8 inches as soon as possible after they have been laid and checked. After the line is complete, the upper end should be permanently sealed so that water can enter only at the joints (Fig. 290).

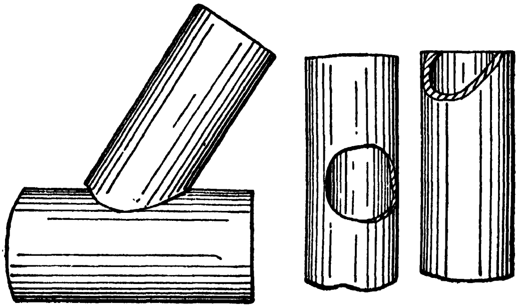


Fig. 289.—A hand-made junction.

In laying tile, care should be exercised to see that the grade is faithfully maintained. The ditch has been finished to grade,

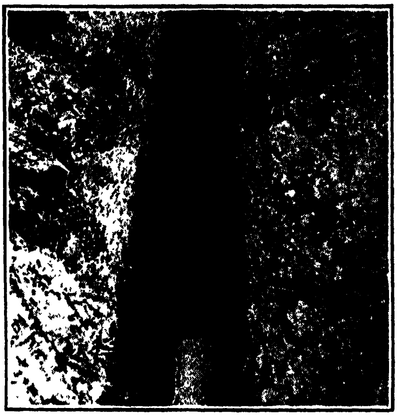


FIG. 290.—Upper end of tile line showing last tile plugged to keep out dirt and small animals. (*Courtesy of Mason City Brick and Tile Company.*)

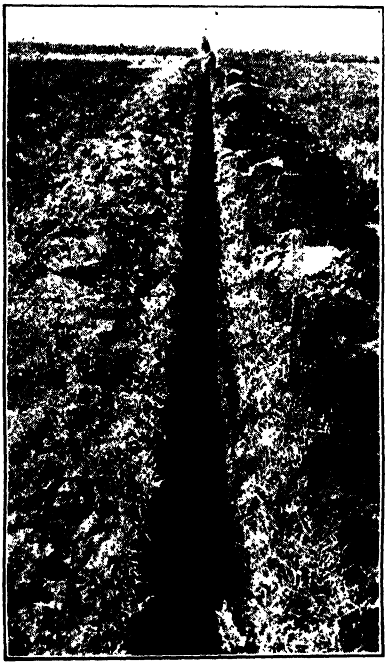


FIG. 291.—A line of tile in place ready for inspection and blinding. (*Courtesy of Mason City Brick and Tile Company.*)

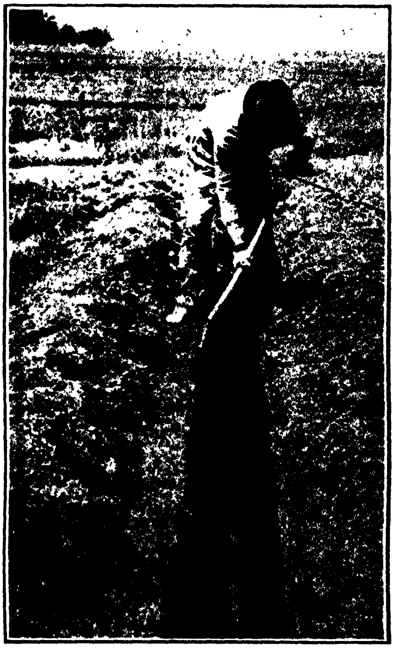


FIG. 292.—Blinding the tile by carefully shaving off top soil from the sides of the trench. (*Courtesy of Mason City Brick and Tile Company.*)

and, if properly done, it should not be tampered with, as more excavating or filling will affect the grade.

480. Checking Grade.—After the tile is placed in the ditch and before any earth is put in (Fig. 291), the grade of the tile should be checked. This is done by using a level. Set the level up where a good portion of the ditch can be seen. Then have a man hold the level rod on top of the tile in the ditch. It would be best to start at the highest end. Read the rod and then have the rodman move 25 feet along the line of tile and here make another reading. If this last reading has the desired fall, all is well, and the rodman moves 25 feet more, where another reading is made. This operation is continued until the entire line has been covered.

Fig. 293.—Filling trenches with plow.

Fig. 294.—Type of scraper well adapted to filling trenches and digging shallow ditches.

Should the readings prove that the tile is not getting the proper fall, the trouble should be located, and the tile placed at proper grade. Reasonable allowance should be made, however, for small variations from the theoretical grade. This checking is a very necessary precaution and should always be performed to make certain that the work is properly done. Running water in a tile line is a valuable aid in checking its grade.

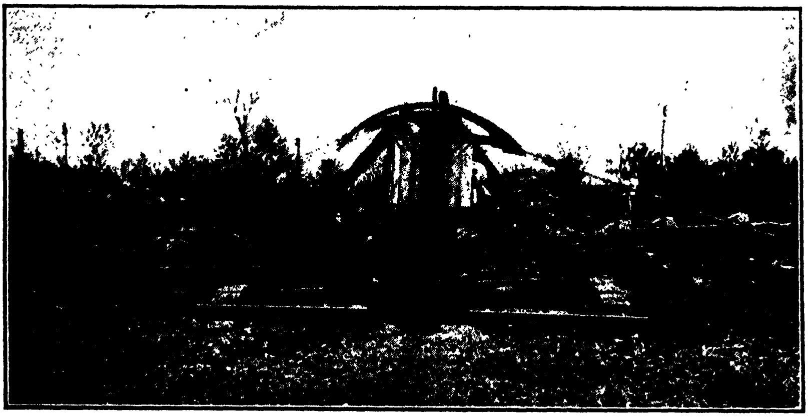


Fig. 295.—Rear view of the Sargent backfilling machine.

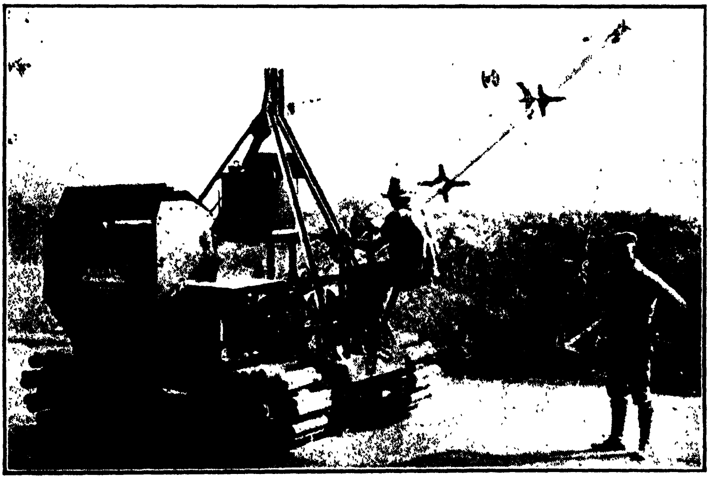


Fig. 296.—A common type of power backfilling machine.

481. Refilling Ditches.—After the tile is checked, the ditch is ready for refilling (frequently called *backfilling*). The first earth should be carefully shaved off the sides of the trench (Fig. 292) and placed at the sides of the tile. Then 3 or 4 inches should be placed on top of the tile with shovels. All the rest of the dirt can then be placed in the ditch in any way that seems best and cheapest. It can be put in by hand or by the use of a plow with a long evener (Figs. 293 and 294). Sometimes, scrapers or road machines are used. Specially constructed power-operated backfilling machines are on the market and are economical where very large quantities of earth are to be handled (Figs. 295 and 296).

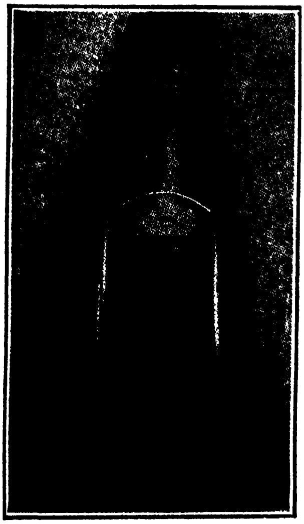


FIG. 297.—Sand shield. In sand or quicksand in a wet trench, a sand shield of galvanized iron is used to prevent the sand from running in and spoiling the bed of the trench. The bed of the trench is finished inside this shield and the length of tile laid, the sand shield is then pulled forward its own length and the process repeated. This process insures laying the tile to grade.

Often, in going through quicksand (Fig. 297) or fine, tight soils which would have a tendency either to fill the tile or pack so close around it as to hamper drainage, other materials are placed in the ditch on top of the tile. Straw, hay, corncobs, broken stone, cinders, coarse sand, and gravel have all been used with good success. Sometimes, when the sand is very fine and is accompanied by water, it is necessary to wrap the joints of the tile with burlap or thick straw to keep it from running in. By the time the burlap rots (if ever), most of the excess water will have been dissipated, and there will be no further need for it.

If the bottom of the trench is very soft and unstable, it may be necessary to support the tile on boards or short piles to keep them from settling unevenly. A small amount of topsoil thrown in the bottom of such a trench aids materially.

482. Specifications for Laying Tile Drains.—The farmer often does not wish to be troubled with the details of installing the tile and, therefore, prefers to have the work done by contract. Where this is done, contract and specifications must be written up and duly signed. The following is given as a sample contract and specifications to serve as a guide:

CONTRACT AND SPECIFICATIONS FOR TILE DRAINS

It is hereby agreed, between .... Employer, and .... Contractor, that the said .... will construct the following named or described tile drains in accordance with the specifications herein set forth, at the prices herein named, and that he will begin the work on or before .... and will complete the same by ...., unless the work is delayed by conditions for which he is not responsible or which are beyond his control.

The tile drains to consist of the following:

....

....

further described by plat and other papers prepared by the engineer in charge.

The prices to be paid for the work, subject to the conditions prescribed in the specifications, are as follows:

....

....

The digging of the ditches must proceed after the usual and approved manner, maintaining the alignment and grade in accordance with the stakes set and depths of cut given by the engineer.

The grading of the bottom must be done by means of the line-and-gage method, unless otherwise agreed to by the employer. Brackets or targets must be set up at three or more stations at a time and their relative positions noted, so as to discover any errors which may occur and corrections made if found necessary.

The laying of the tile must be done in a neat and workmanlike manner upon a bottom as firm as is practical under existing conditions, and they must be left uncovered until inspected and approved by the engineer in charge, unless it is necessary, as when sand is encountered, to cover them immediately, in which case they are to be covered with clay or other suitable material. All openings caused by making turns or otherwise must be securely covered by broken pieces of tile. Junctions with branch tile must be carefully and securely made and, in case the branches are of 12-inch tile or larger, are to be held and supported by a covering of concrete, unless Y pipe are used. All junctions must also be joined to the main in such a manner and at such an angle as to retard the flow of water as little as possible.

After the tile have been inspected and approved by the person in charge, they must be covered with soil so that complete filling may be made directly upon them.

The contractor must assume all risks from storms and caving in of ditches and must leave each line reasonably free from sand and mud.

All tile must be delivered by the employer and distributed in a straight line along the side of the ditch where they are to be used, and from .... to .... feet distant from it.

The contractor must use care to see that no soft or otherwise objectionable tile are laid.

All survey stakes must be preserved, and every means taken to do the work in a first-class manner.

In case the contractor neglects to proceed with the work within a reasonable time or refuses to correct faults in the work as soon as they are pointed out by the person in charge, the employer may declare the contract void, and the contractor, upon being paid 80 per cent of the value of the completed drains at the price agreed to in this contract, shall release all claims on the work.

The contractor must be responsible for all the work and, in case he sublets any part of it, shall see that the party to whom he sublets it is paid for the same.

The contractor shall furnish all tools for doing the work. In case it is necessary to use curbing for the ditches or outside material is necessary to support or protect the tile, the employer shall furnish the same upon the ground convenient for use.

Unless otherwise agreed upon, the contractor may claim 80 per cent of the value of completed and accepted work at the contract price once a month. A payment of money to be used in carrying on of the work, however, shall not be considered as an acceptance of any portion of the work in such a manner as to release the contractor from any obligation to correct faults in the same if pointed out later. Twenty per cent of the contract price will be retained until the entire job contracted for has been completed and accepted, at which time the whole amount due shall be paid.

In case of any dispute or doubt about the provisions of the contract by or between the parties interested herein, or if a change in plans is made necessary by unforeseen conditions, or better to attain the end sought, the engineer in charge shall act as umpire in the adjustment thereof, and his decision shall be binding upon both parties.

Dated at.................................this...............
....................................day of.............A.D. 19.....

....
Employer

....
Contractor

References

Miller, Wendell P.: "Installing Farm Drainage Systems," *Ohio State Univ. Bull.* 10, Vol. XVIII, 1922–1923.

Roe, H. B.: "Farm Drainage Methods," *Univ. Minn. Bull.* 217, 1924.

Lynde, H. M.: "Farm Drainage in North Carolina," *N. C. Agr. Expt. Sta., Bull.* 234, 1915.

CHAPTER XXIX

DRAIN-TILE ACCESSORIES

483. Outlet Protection.—There are five things against which outlets must be protected—caving banks, small animals, backwater, tramping of stock, and, in cold climates, damage from alternate freezing and thawing.

484. Protection against Caving Banks.—Caving banks are caused by the water running out of the end of the tile and washing away the bank underneath the tile, thus allowing the first joint of the tile to fall into the open ditch. The water repeats the same thing on the next piece of tile after the first tile has fallen, and this process goes on until the outlet has receded far into the field.

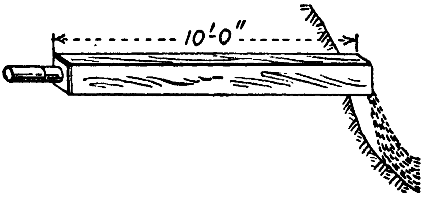


Fig. 298.—Box drain for outlet.

There are three means used to prevent this—box drains, vitrified tile, and concrete or brick walls.

The box drain consists of building a box 10 feet long of 2-inch material and of a wood which is very durable, as cypress, oak, etc. This box is square, with an opening at one end of sufficient size to allow the end of the tile to enter it (Fig. 298). The opposite end has its opening on the underside, and through this opening the water discharges into the ditch. The long length of the box prevents the water from undermining it enough to allow it to fall into the ditch. The greatest disadvantage of this method, however, is that it is not durable.

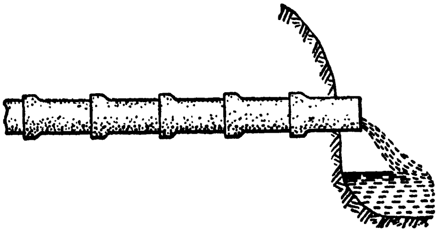
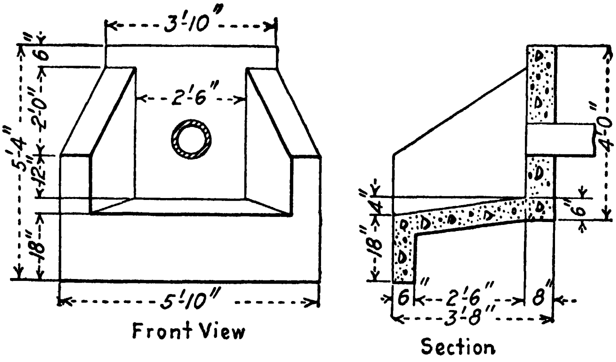


Fig. 299.—Vitrified-tile outlet.

Vitrified-tile protection consists of using the required size of vitrified sewer tile and cementing the last three or four joints together (Fig. 299). This prevents the water from undermining a sufficient length of it to allow the tile to fall into the ditch. This method is, of course, more durable than the box-drain protection.

Brick or concrete walls are by far the best and should, whenever possible, be used as absolute insurance against caving banks. Figure 300 shows the proper size and shape for this outlet protection.



Front View

Section

FIG. 300.—Concrete bulkhead.

485. Protection against Small Animals.—Small animals such as muskrats, rabbits, etc., often seek habitation in tile drains, especially during a dry time. They build their nests or get themselves held fast in the drains, an event which, of course, causes the drains to stop up. To protect against this trouble, iron rods should be placed across the end of the outlet of the tile to prevent the animals from gaining entrance. The rods may either be fixed permanently in place or may be removable.

486. Protection against Backwater.—This protection is necessary only where a submerged outlet is used. In placing tile drains, the question of the outlet should be carefully considered, and, whenever possible, a submerged outlet should be avoided. But where it must be used, protection should be taken against the flood water backing up into the tile. Flood water carries considerable sediment, and, if allowed to back up into the tile and become stationary, it will drop the sediment, thus filling up the tile.

The automatic outlet gate is the best protection against this (Fig. 301). This gate can be fitted to the end of the tile, or box drain, but it is better to use a cast-iron pipe at the end of the drain to fit the gate, because it can be filed so that the latter will fit closely. The gate is made of two thicknesses of 1-inch boards thoroughly creosoted. The hinge can be made at any blacksmith shop. The gate is automatic in its action; when the water in the open ditch is of sufficient height to prevent the water in the tile from running, it closes. When not, it opens and allows the water in the tile to drain out.

Such a gate is manufactured commercially by the California Corrugated Culvert Company of West Berkeley, Calif. It is generally sold already attached to a long corrugated iron pipe, and has proved very satisfactory, especially where outlets are subjected to periodic inundation. (See Fig. 110.)

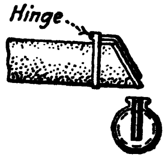


Fig. 301.—Automatic outlet gate.

487. Protection against Tramping of Stock.—Well-located outlets are seldom disturbed by tramping cattle. Where the tile are placed very shallow, however, and the end is left entirely exposed, stock are attracted by the water generally found in outlets in dry seasons, and they may do serious damage by crushing one or more of the tile or by prying them out of line. The remedy is to place the tile deep enough to allow a sufficient earth covering, or, if this cannot be done, cattle can be kept away by dumping poles and brush near the tile or by building a fence around the outlet.

488. Protection against Freezing and Thawing.—In regions where the winters are severe, some thought needs to be given to the disintegrating action of alternate freezing and thawing. The more porous a tile is the greater the damage is likely to be, because more water is held in the pores to be frozen. Ordinarily, tile laterals and mains are buried below the frost line which seldom penetrates more deeply than 2 or 3 feet, but wherever they are exposed to drafts of air, as below surface intakes and for 20 to 25 feet back from outlets, hard-burned, vitrified tile should be used, or some other non-porous material. Common tile should not be piled on top of the ground, as is frequently done, and left there unprotected all winter.

489. Clogging by Roots.—Whenever tile are placed closer than 50 to 75 feet to water-loving trees, especially willows, roots are very likely to enter the tile and, in time, fill them completely with a dense, fibrous mass. The 20-inch tile shown in Fig. 302 was taken from a depth of 11 feet and found in the condition illustrated. The tree nearest to this particular tile was 25 feet away. One hundred and thirty-five feet of tile were removed and replaced with bell-and-spigot sewer pipe, the joints of which were sealed with cement mortar. Notwithstanding this precaution, roots continued to enter through very small crevices in the mortar and cause trouble. Eventually, it was necessary in this case to kill all the trees in the vicinity.

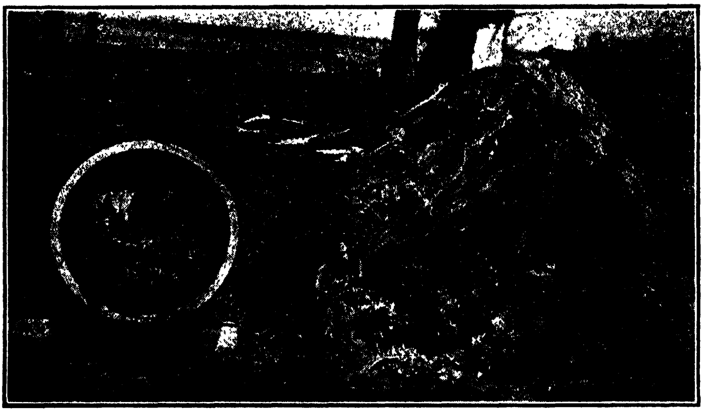


FIG. 302.—Some tree roots have a great affinity for tile drains.

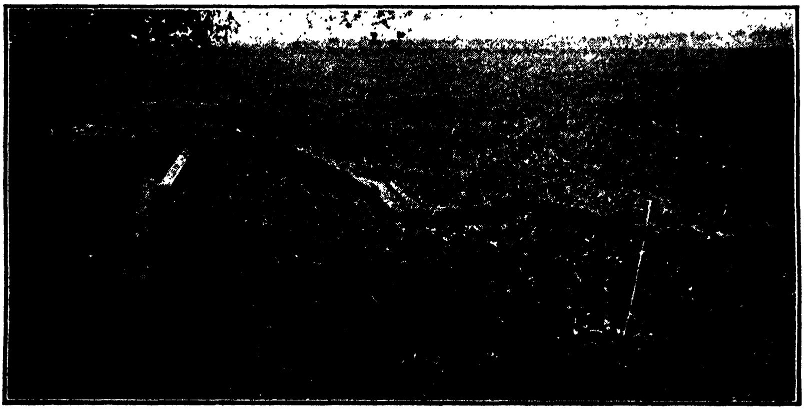


FIG. 303.—Tenacious, snake-like mat of willow roots which was removed from a 12-inch drain.

It has been said that soaking tile in a carbolineum solution before laying them or mixing rock salt in the blinding soil will prevent or discourage the entrance of roots. The only safe rule is to keep the tile outside the danger zone or else sacrifice the tree.

It would seem probable that the roots of alfalfa or other deeprooted plants might enter tile lines and cause trouble, but the authors have never heard of a case where this has happened.

490. Cleaning Tile.—Sometimes tile lines become filled with sediment (mud and sand) to an extent sufficient to cause them to cease functioning, and it becomes necessary to clean them out. The usual procedure is to dig holes down to the tile at intervals of 25 to 50 feet, depending upon the size of tile and the amount of sediment to be removed, and take out one or more individual tile at each hole. Next, a light, stout string is threaded through the tile between two adjacent holes, and a rope is attached to one end of the string and pulled through. A strong bag, filled with straw and large enough to occupy about three-fourths of the area of the tile, is then securely fastened to one end of the rope. By pulling on the other end, sediment is gradually forced out at the opening toward which the bag is being drawn. Here it is bailed out and wasted on the surface of the ground. It is a good plan to tie another rope to the opposite end of the bag so that it can be drawn back and forth several times and thus clean the tile thoroughly. After one section has been cleaned in this way, the process may be repeated as many times as may be necessary on the other sections. A small amount of mud will probably remain in the tile after this operation, but it will be so stirred and loosened that it will be washed out after the first heavy rain.

The only thing that may be difficult is to get the first string threaded through. Mice and other small animals have been induced to crawl through the tile, pulling behind them the string, to which they are tied, and sometimes flexible or jointed fishing poles have been used for this purpose. The most satisfactory way, however, is to use specially constructed sewer rods. These come in 4-foot lengths and can be attached or detached only when held at right angles with each other. The rope is tied to the forward end of one rod which is pushed into the tile. Another rod is joined, and the two rods pushed 4 feet farther, this process being continued until the rope appears at the next opening.

If large quantities of water are available under good pressure, the tile may be cleaned by flushing, but this is seldom possible. Another way is to use a common diaphragm pump to remove the sediment, if it is mixed with enough water to allow it to flow.

491. Surface Inlets.—Surface inlets are used to allow surface water to flow directly into the tile without going through the soil. Often conditions are such that these are desirable. For example, in the case of hollows or sinks in a field, where the land is flat and heavy rainfall is to be taken care of; and in barnyards and lots around the buildings.

There are three principal methods of building surface inlets—with broken stone, with vitrified tile, and with concrete or brick.

The broken-stone inlet is the simplest, cheapest, and least durable (Fig. 304). It consists of refilling the ditch with broken stone instead of dirt at the points where the surface water is to be taken into the tile. The disadvantage of this method is that dirt will fill up the voids between the stones.

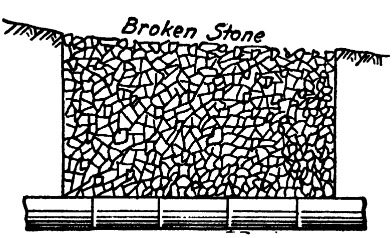


FIG. 304.—Surface inlet to tile.

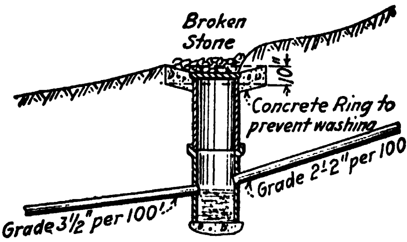


FIG. 305.—Silt basin at change of grade in tile drain.

The vitrified-tile inlet is reasonable in cost and very durable. It is, perhaps, the most used of the three types (Fig. 305). It consists of using vitrified sewer tile of the desired size, standing them up in the ditch, and connecting each side to the tile drain, placing enough lengths of the vitrified tile on top of each other to bring one end to the surface. The end at the surface is then covered with a cast-iron grating which allows the water to flow into the tile but keeps out trash.

The brick or concrete inlet is most expensive of all but is very durable. It is used for large inlets. These inlets are usually built square and extend from the line of tile to the ground line. The upper opening is covered with a grating of iron rods.

492. Silt Basins.—Silt basins are used where a considerable amount of silt is washed into the surface inlets, or where there is a change of grade sufficient to cause silt to be put down. They are built the same way as the last two surface inlets named, except that, instead of stopping the lower end of the inlet at the bottom of the tile, it is carried 1 foot or 18 inches lower, in order to pro-

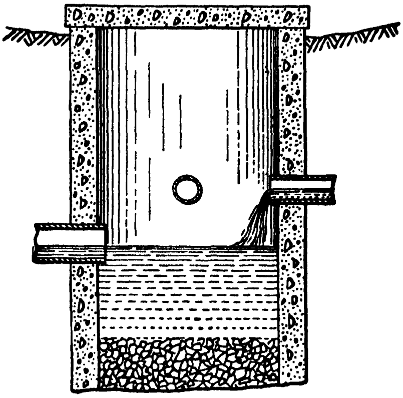


FIG. 306.—Concrete silt basin.

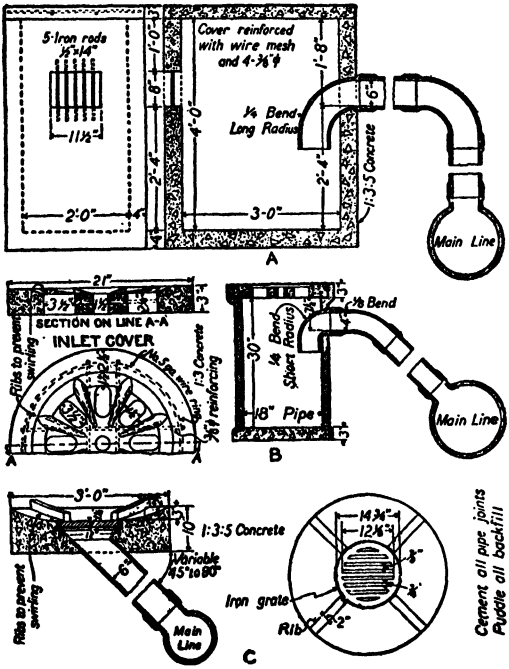


FIG. 307.—Types of surface-water inlets for closed drains. Recommended by the U. S. Department of Agriculture.

vide a place for the silt to collect (Fig. 306). This silt is cleaned out through the opening at the top. The surface-inlet feature can be included or not in the silt basin, as one sees fit. If it is not used, a removable cover should be placed over the upper end. This cover may be buried below plow depth if desirable. Sometimes, it is desirable to create a silt trap at the ground surface by constructing a concrete bowl or depressed ring around the vertical tile just below the iron grating. All inlets or silt basins require periodic inspection and cleaning at reasonable intervals to keep them in good working condition.

CHAPTER XXX

ESTIMATING COST OF TILE DRAINAGE

493. Preliminary Estimate of Cost.—It is often desirable to prepare a preliminary estimate of cost before any surveying has been done, in order to determine the approximate expense of the drainage work to be undertaken. The following figures will be of assistance in doing this:

NUMBER OF TILE NEEDED FOR LATERALS TO DRAIN ONE ACRE OF GROUND WITH DIFFERENT SPACINGS (MAINS NOT INCLUDED)

Number of Feet Apart	Number of Feet per Acre
20	2,178
25	1,742
30	1,452
33	1,320
40	1,089
50	872
60	726
66	660
70	623
80	545
90	484
100	436
125	348
150	291
200	218

494. Bill of Materials.—After the survey has been made and the tile lines plotted upon the map, a bill of materials should be made out. This bill should contain the number of feet of each size of tile needed. The number of tile specials and materials needed for accessories should also be included.

495. Estimating Cost.—The bill of materials will serve as a basis for estimating the cost of installing the drainage system. The total cost can be divided into five parts for convenience in computing—cost of tile, cost of hauling and distributing, cost of installing tile, cost of accessories, and cost of engineering and superintendence.

496. Cost of Tile.—The prices at which manufacturers usually sell tile include delivery on board freight cars at the nearest railroad station. These prices vary from year to year and in different sections of the United States during any 1 year, so it is impossible to give accurate figures that would apply everywhere and at all times. It is believed, however, that the figures given in the following table represent average prices that are close enough for estimating purposes. These prices have remained fairly constant for the past 10 years and are likely to be good for several years to come. Before actually placing an order for tile, it is, of course, desirable to obtain quotations from several manufacturers and select the one whose product seems most advantageous.

TABLE 41.—PRICES OF CLAY DRAIN TILE[1]

Kind of tile	Size, inches	Price per 1,000 feet	Price per rod
Common tile	4	$ 28	$ 0.46
	5	40	0.66
	6	50	0.82
	7	70	1.15
	8	90	1.48
	10	160	2.64
	12	220	3.66
Vitrified tile	14	300	5.00
	15	375	6.25
	16	435	7.20
	18	523	8.60
	20	676	11.10
	22	855	14.10
	24	957	15.75
	27	1,410	23.20
	28	1,629	26.80
	30	1,810	29.80

[1] As of Jan. 1, 1939, F. O. B. nearest railroad station, which is assumed to be 100 miles from the factory. Freight is figured at 8 cents per 100 pounds. In sizes smaller than 10 to 12 inches, prices of concrete tile are higher; but for the larger sizes, they are very materially lower. The prices quoted have not varied materially for the past 10 or 12 years, and they are likely to remain the same for several years to come.

497. Cost of Hauling.—The cost of hauling tile from the nearest railroad station and distributing them in the field to be drained should be estimated, although the farmer will often do it himself, in which case, it will not call for an actual outlay of cash. Table 42 gives the weight of various sizes of tile. With the aid of this table and the bill of materials, the number of tons of tile can be determined. With the number of tons to be hauled and the distance known, Table 43 will give data needed to make a final estimate of the cost of hauling and distributing, with team.

TABLE 42.—WEIGHT OF CLAY DRAIN TILE[1]

Size, inches	Weight per foot, pounds	Average carload, feet	Number of feet per ton
4	6	6,500	334
5	8	5,000	250
6	10	4,000	200
7	12	3,300	166
8	15	2,600	133
10	25	1,600	80
12	32	1,200	62
14	45	800	44
15	50	650	40
16	55	500	36
18	70	400	27
20	85	332	23
22	95	320	21
24	110	300	18
27	150	250	14
28	165	220	12
30	200	160	10

[1] Weight of concrete tile from 40 to 60 per cent heavier.

TABLE 43.—HAULING COST PER TON

Hauling	Cost per Ton
1 mile	$0.95
2 miles	1.15
3 miles	1.35
4 miles	1.95
5 miles	2.20

This table of cost is with the road in fair condition and allowing the team and driver $5 per day.

In regard to the cost of hauling by truck, a study was made of all available statistics bearing on that subject. Perhaps the most pertinent data are those presented in *Bulletin* 931, U. S. Department of Agriculture. In this bulletin, the average cost of operating 831 trucks (average gross weight 2.8 tons), 87 per cent over dirt roads and 13 per cent over gravel and paved roads, was 23.40 cents per truck mile or 8.36 cents per gross ton-mile. When garage and insurance expenses are added and a reasonable allowance is made for profit, a fair charge for hauling tile by truck would seem to be 30 cents per net ton-mile. The cost of loading and distributing in the field, which would vary with local conditions, must be added.

Roe gives an average of 1.51 hours per ton-mile for either team or truck.

498. Cost of Installing Tile.—This cost is, perhaps, the hardest of all to get at, because it varies with different soil conditions, prices of labor, weather conditions, and many other factors. In order to use something that has a chance of being adapted to varying conditions, Table 44 is included, which shows the cubic yards of earth excavated per 100 feet of ditch for tile of varying sizes. The cost of moving earth by hand can be determined by inquiry in any locality. In general, the yardages shown to the left of the heavy black line can be moved for from 25 to 35 cents per yard, with labor at $2.50 per day, while those on the right can be moved for from 35 to 70 cents per yard, depending entirely upon conditions. These prices include digging the ditch, laying the tile, and blinding.

TABLE 44.—CUBIC YARDS EXCAVATED PER 100 FEET OF DITCH FOR TILE[1]

Depth of ditch, feet	Size of tile										
	4, 5, and 6	7 and 8	10	12	14	15	16	18	20	22	24
3	11.1	12.9	14.8	16.7	18.4	20.3	22.2	24.0	25.9	27.8	29.8
4	17.2	19.7	21.0	22.2	24.6	27.1	29.6	32.0	34.5	37.0	39.4
5	27.8	29.3	30.7	32.4	33.9	37.0	40.0	43.1	46.3	49.3	52.4
6	33.3	35.1	36.9	38.9	40.7	44.4	48.0	51.8	55.3	59.1	62.9
7	43.0	45.4	47.4	49.8	51.8	53.9	56.0	60.4	64.8	69.0	73.4
8	49.2	51.9	54.2	56.9	59.3	64.0	69.0	74.1	78.8	83.8	88.9
9	61.0	64.0	66.7	69.3	72.0	77.7	83.3	88.7	94.3	100.0	105.3
10	67.8	74.1	77.0	80.0	86.3	92.6	98.5	104.8	111.1	117.0	123.3
11	81.5	88.0	91.7	95.0	101.9	108.4	115.3	122.2	128.7	135.7	142.6
12	96.0	103.6	107.6	111.1	118.2	125.8	133.3	140.4	148.0	155.6	162.7

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[1] PARSONS, "Land Drainage."

The cost of backfilling the ditch depends, to a large extent, upon the method used. Backfilling with teams will require from 0.42 to 1.06 hours for man and team for each 100 feet of ditch. The low figure would apply for 4- to 6-inch tile, not over 4 feet deep, while the other figure would apply where there are some large as well as small tile and at varying depths.

499. Common Method of Estimating Installation Cost.—The most common method of estimating the cost of installing tile is by use of Table 45, which gives prices in dollars per rod for installing the smaller sizes of tile up to 14 inches in diameter and in dollars per 100 feet for the larger sizes. Costs are most conveniently computed in the units given, and, where the figures are dependable, this is the best and simplest method to employ. To illustrate the use of this table: Suppose that the average cut, as taken from the profile of a given section of 6-inch tile, is 4.3 feet. The cost per rod of installing this line of tile would then be the cost for 4-foot work ($0.85) plus the cost

TABLE 45.—COST OF DIGGING TRENCH, LAYING TILE AND BACKFILLING
Average Soil Conditions (Clay and Loam)—No Rock or Hardpan

Size of tile, inches	Price per rod		
	Average cut 3 feet deep or less	Average cut 4 feet deep	Add for each one-tenth-foot overcut
4, 5, or 6	$0.55	$0.75	$0.03
7 or 8	0.75	1.00	0.03½
9 or 10	0.95	1.25	0.04
12	1.25	1.50	0.04½

Size of tile, inches	Price per 100 feet								
	Average depth of cut, feet								
	4	5	6	7	8	9	10	11	12
14	$10.60	$15.00	$20.25	$26.25	$33.10	$40.60	$57.50	$72.50	$93.75
16	11.85	16.90	22.50	28.75	36.85	47.50	60.00	76.20	98.75
18	13.75	18.25	25.00	31.25	40.00	50.00	62.25	82.50	105.00
20	15.00	20.65	27.50	34.40	41.90	54.00	68.70	87.50	111.25
22	16.50	22.50	31.25	37.50	48.75	60.00	76.30	93.75	117.50
24	18.10	24.40	35.00	43.80	56.30	68.80	83.75	101.25	125.75
26	21.00	26.30	38.75	50.00	63.75	78.75	91.25	108.75	130.00
28	......	31.25	43.80	56.25	71.25	88.75	101.00	116.25	135.00
30	......	35.00	48.75	62.50	78.75	97.50	108.75	121.25	140.00

Where board is furnished, these prices should be reduced about 25 per cent.

of digging three-tenths of overcut at 3 cents per tenth or 9 cents. The total cost per rod in this case would, therefore, be \$0.85 + \$0.09 = \$0.94. Had the average cut been 3½ feet, the cost would have been \$0.55 + \$0.15 = \$0.70.

The prices for installing large tile may be taken directly from the table for even cuts between 4 and 12 feet. If the depth of cut falls between two even numbers of feet, the cost must be interpolated. For instance, if an 18-inch tile line is to be installed 8.5 feet deep, the cost per 100 feet would be $\frac{40.00 + 50.00}{2} =$ \$45. If the depth is to be 8.3 feet, the corresponding cost will be \$43. The rate of increase per tenth is \$1. Rates of increase for other depths and other sizes are determined in a similar manner.

500. Man-hour Basis.—This method of estimating the installation cost of tile drains is by far the best, because it allows to be estimated the number of hours it will take to do the job, and this multiplied by the prevailing rate for labor will give the cost of installing. H. B. Roe, of the University of Minnesota, in *Technical Bulletin* 47, of the Agricultural Experiment Station of that institution, gives the following as the results of his investigations:

> This schedule—which is built on a man-hour labor unit—is developed from the trenching data on eighteen farm drainage systems put in from 1908 to 1921 under the supervision of members of the drainage staff of the Minnesota Agricultural Experiment Station.
>
> The character of digging falls naturally into three classes: easy, average and hard. Three schedules are presented covering these three classes. Of the eighteen projects only two fall within the first class (easy digging), both of these being in peat; fourteen projects fall within the second class (average digging), almost wholly in mineral soil; and two fall within the third class (hard digging), also in mineral soil.
>
> Under easy digging were included those classes of soil and soil conditions which presented no very serious obstacles to spading and casting—light soils of rather loose texture, free from roots, stumps, loose gravel, stones or boulders, in which the spade settled readily under hand pressure or a slight pressure of the foot—and where soil moisture was present in just sufficient quantity to give such firmness to the soil as to make the trench walls self-sustaining and the spade slice coherent enough for easy casting. This class of digging includes such soils as peat reasonably free from tough fibers, roots, stumps, etc.; light, porous, sandy loams; sandy clays, and the finer damp sands.

Under average digging were included those soils or soil conditions where there was required a considerable, but not excessive, pressure with the foot to settle the spade and a considerable effort to cast, where there were encountered occasional obstacles such as a light shell of frost, possibly requiring the occasional use of the pick, some cobblestones, or a boulder, or a stump now and then, or material which, while easily spaded, is difficult to cast because of its weight, but where the spade slice was, in general, sufficiently coherent to make casting tolerably easy, and where caving of trench walls was infrequent. Such conditions are of the most frequent occurrence in ordinary prairie soils such as loams, clays, and clay loams, except after protracted periods of drouth and during those periods of the year when frozen ground must be reckoned with.

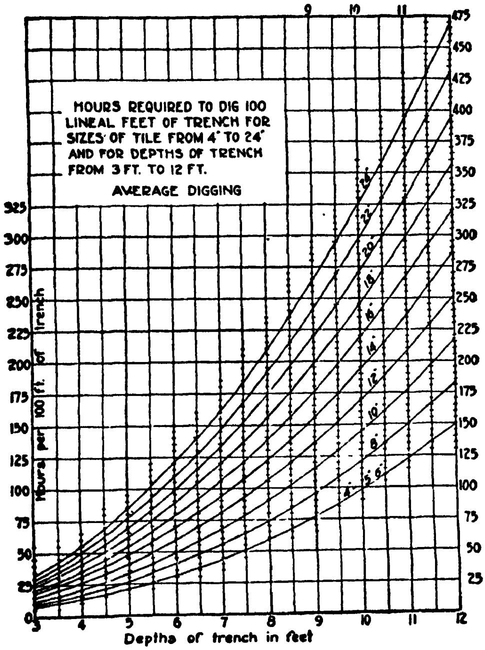


FIG. 308.

Under hard digging were included all digging conditions not included under easy and average digging; as, for example, such soil moisture or soil texture conditions as cause a fairly constant tendency for the trench walls to cave, looseness, heaviness, or wetness of material that makes casting difficult; soil so hard, either from drouth or on account of its natural character, that spading of it, in the usual manner, is rendered extremely difficult or impossible so that frequent use of the pick or of explosives must be resorted to; heavy sand and gravel; frequent occurrence of cobblestones, boulders, stumps, etc. This class includes ground frozen to a considerable depth, hardpan, cemented gravel, coarse loose sand, heavy gravel, very stony soils of any class whatsoever and soils so hard, from lack of moisture, as to be difficult or impossible to spade in ordinary fashion.

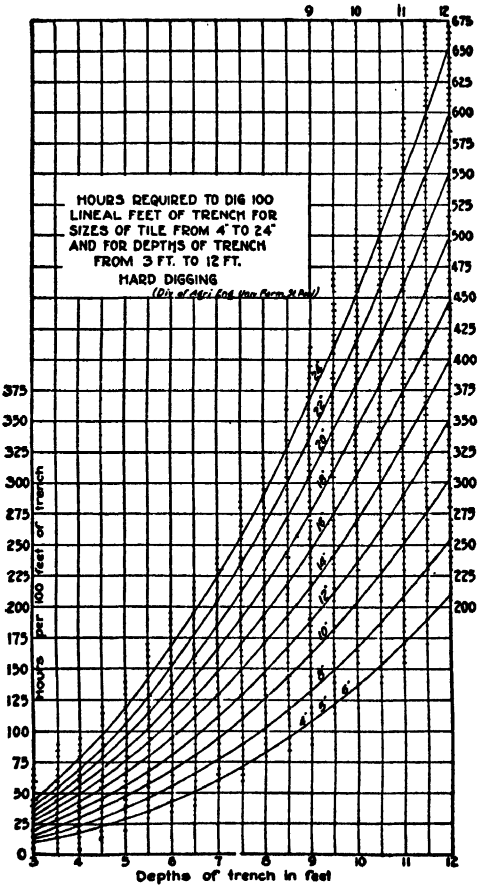


FIG. 309.

Figures 308, 309, and 310 give the number of hours of man-labor required to dig, lay, and blind 100 feet of drain tile of various sizes and for different depths. The three different figures are for the various rates of digging. Figure 311 is for the backfilling.

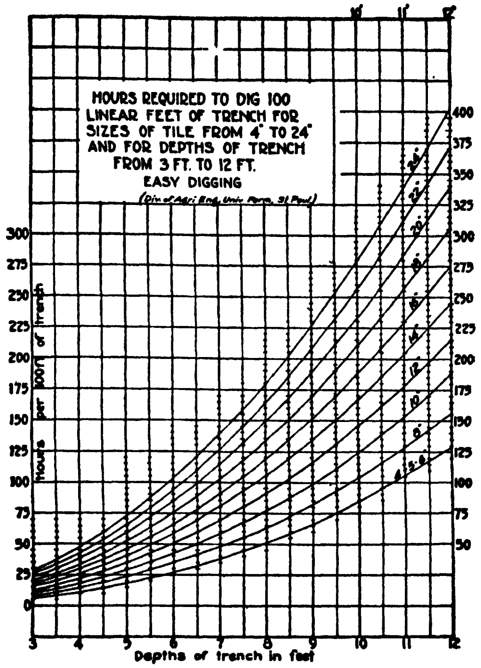


FIG. 310.

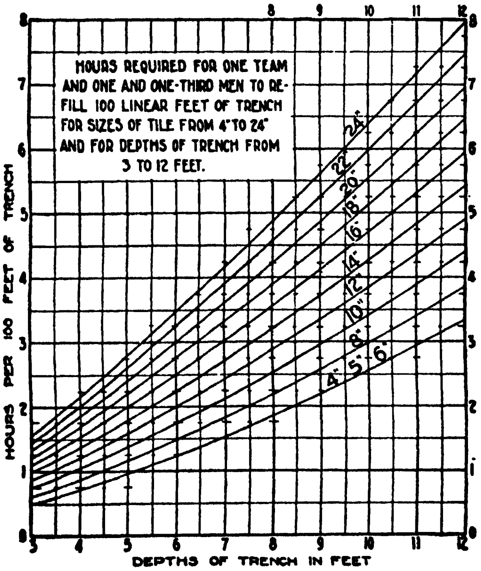


FIG. 311.

501. Cost of Accessories.—The cost of accessories should be figured from the materials and labor needed. The amount of brick, cement, sand, gravel, etc., should all be made out, and the cost figured at market prices. Usually, the cost of inlets and outlets is not over $5 to $10 each.

502. Cost of Engineering and Superintendence.—Where the farmer is able to do this himself, it need not be taken into account, but in cases where it is to be included, it usually runs about 5 per cent of the total cost. On all but the smallest and simplest jobs it is false economy to try to avoid engineer's charges, for, usually, engineers more than save their fees by effecting economies in design and construction of which the farmer would not think. In addition, a competent engineer will insure that the work will be properly done, and his fee may be considered somewhat in the nature of a premium on an insurance policy, guaranteeing the success of the system.

Problems

64. A farmer lives 4 miles from a station on a railroad and wishes to have the following tile put in 3½ feet deep by contract, with an engineer to superintend the work. Compile an estimate of cost.

10,200 feet of 4-inch tile.
5,000 feet of 5-inch tile.
900 feet of 6-inch tile.
800 feet of 8-inch tile.
1,000 feet of 10-inch tile.

No inlets will be used, but three outlets will need to be constructed at a cost of $7.50 each.

65. A farmer lives 5 miles from a railroad station and wishes to have the following tile put in 4 feet deep by contract, doing his own engineering and superintending. Compile estimate of cost.

15,000 feet of 4-inch tile.
4,000 feet of 6-inch tile.
1,000 feet of 8-inch tile.
1,500 feet of 12-inch tile.
500 feet of 18-inch tile.

No inlets but four outlets will be needed at a cost of $5 each.

66. Refer to Art. 493 and compute the cost of installing 4-inch tile 3 feet deep on 1 acre for the various distances apart.

CHAPTER XXXI

SPECIAL METHODS OF DRAINAGE

503. Vertical Drainage.—It is the custom in many localities scattered over the United States to drain sink holes and other land having no gravity outlet into vertical wells which penetrate into a water-absorbing stratum some distance below the ground surface. This kind of drainage is more or less speculative in character, because it is impossible to secure exact and complete data concerning the underground formations into which surface water will be discharged. Sometimes the wells function perfectly for a few weeks or months and then cease to take any more water because there is no escape from the stratum into which the water is being drained.

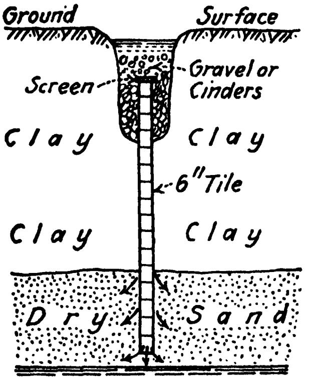


FIG. 312.—Shallow vertical drain dug with post auger.

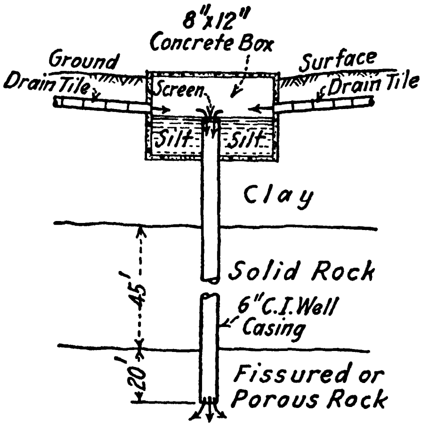


FIG. 313.—Deep vertical drain drilled with power outfit.

Where conditions are favorable, however, this method of drainage possesses considerable merit. In northern Iowa, a number of wells exist which have given complete satisfaction for more than 30 years, and they make possible the drainage of many acres of excellent land which would otherwise remain unreclaimed.

Most of these wells discharge into a stratum of pervious rocks, connection with which is maintained through an iron casing extending to within 4 or 5 feet of the surface. The log of one such well which serves as the outlet to 160 acres of land is as follows:

0 to 45 feet	earth
45 to 55 feet	rock
55 to 56 feet	air strata
56 to 80 feet	rock
80 to 102 feet	pervious rock, porosity increasing with depth

Other such wells penetrate a stratum of limestone, found at depths of 50 to 60 feet, and extend 20 feet farther, where a good outlet can usually be secured. One of these limestone wells receives the discharge from two 12-inch tile and drains 320 acres of wet land. Another well, located within 12 miles of two successful ones, was drilled to a depth of 350 feet, and no limestone was encountered. This well was not a success.

In other states, notably Wisconsin, it is possible to puncture a thin layer of clay and secure an outlet into a water-absorbing sand stratum within 20 feet of the surface. These wells can be dug by hand with a post auger, and they are, of course, much less expensive than the deeper ones. It is customary to case shallow wells with 6-inch drain tile and allow the water to enter through a head covering of cinders or gravel. Construction details of each type may be noted in the accompanying illustrations (Figs. 312 and 313).

In spite of the fact that hundreds of vertical drains are in successful operation in various parts of the country, one can never predict with certainty that any proposed well will be a success. Efforts to drain by this method must always be considered as experiments that may or may not be successful. If the level of water in water-supply wells in the vicinity of the proposed drain is appreciably lower than the ground to be drained, the drainage well may be a success. If not, it is certain to be a failure and may even cause damage by creating an overflowing or artesian well. This point should always be thoroughly investigated before the construction of any vertical drain is undertaken.

504. Mole Ditchers.—In a few restricted localities, machines called *mole ditchers* are quite popular, notwithstanding the fact that some consider them impracticable.

The essential features of such a machine are shown in Fig. 314. As it moves forward, the knife edge cuts a narrow slit in the soil as the nose mashes a round hole beneath (Fig. 315).

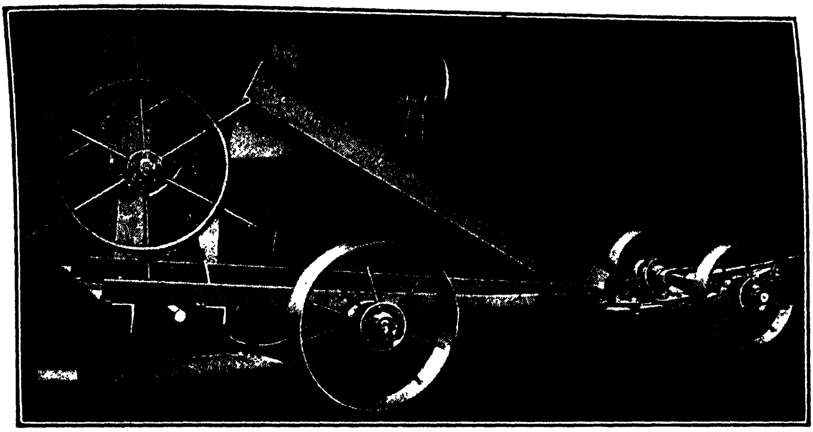


Fig. 314.—Mole ditcher. (*Courtesy of the Killefer Manufacturing Company.*)

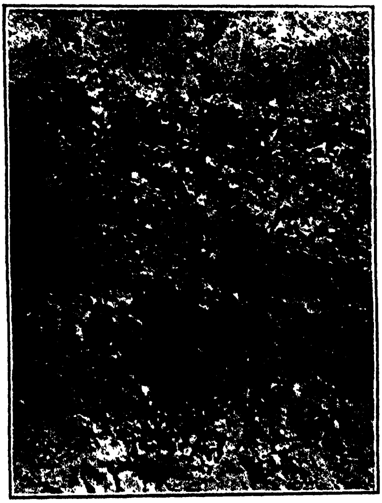


Fig. 315.—Hole made by mole ditcher. (*Courtesy of The Killefer Manufacturing Company.*)

The advantage of this ingenious device is that it saves time and money in construction. Its disadvantages are that (1) the saving in cost is only about 10 per cent of the total cost of the project, (2) it is very difficult to deposit the tile on an even grade when the ground surface is at all uneven, (3) one or more tile may become crushed without being detected, and (4) the soil surrounding the tile is compressed by the steel nose which, in clay subsoils, may not allow the water to enter freely.

Experiments in Michigan,[1] however, indicate that the use of this machine may be of some benefit, temporarily at least, when no attempt is made to line the holes with tile.

505. Draining Cellars.—In some parts of the country, particularly the South, the possibility of having cellars and having them dry is little realized.

Ordinarily, three things need to be done to guarantee that a cellar will be dry: (1) The cellar walls must be made as nearly impervious as possible, (2) the ground-water level must be brought below the level of the cellar floor, and (3) provision must be made to carry out any waste water that might collect there from any source whatever.

To insure that the cellar walls are as nearly watertight as practicable, they should be built of concrete, hard-burned brick, or building tile. If made of concrete, a rich mixture should be thoroughly compacted into the forms and the walls, inside and out, and should receive a coating of neat cement wash, coal tar, or asphalt. If built of brick or building tile, cement mortar should be used, and the walls should be plastered on both sides with a mortar consisting of 1 part cement to 2 parts sand.

Lowering the ground-water level is usually accomplished by placing a drain tile around the outside of the cellar wall and as near the bottom of the wall as possible. Of course, this tile must be given adequate fall (see Chap. XXVI), and it must be provided with an outlet. Instead of filling above the tile with earth, it would be better to use gravel or cinders. If this is impracticable, at least 12 inches of these materials should be put on top of the tile, and the rest of the trench filled with earth.

To provide for the removal of waste water in the cellar, an independent line of sewer pipe is run from the interior of the cellar to the outlet. The end of the pipe opening in the cellar should be located in the floor and should be provided with a perforated iron cover. It would be well to have a trap on this end of the pipe line.

506. Draining Roads.—One of the most important elements of road construction and maintenance is adequate drainage. The

[1] Agric. Eng. Jour. April, 1928.

majority of problems that arise in this connection are concerned with surface drainage. Still, there are conditions, not so rare, that require subsurface drainage, due either to wetness of adjacent land or to seep water. Where these conditions are encountered, tile drains should be installed. These drains should be placed under the shoulders at the sides, seldom under the center of the road. The reason for this is that, should it become necessary to remove the tile, the roadbed would have to be torn up, a process which would be expensive and inconvenient. It is not often that tile needs to be placed on both sides of the road; usually, one side is sufficient. The proper side is the one where seepage first appears so as to cut off the water and keep it from reaching the roadbed. In the case of adjacent wet lands, a little investigation will enable the tile to be placed to best advantage.

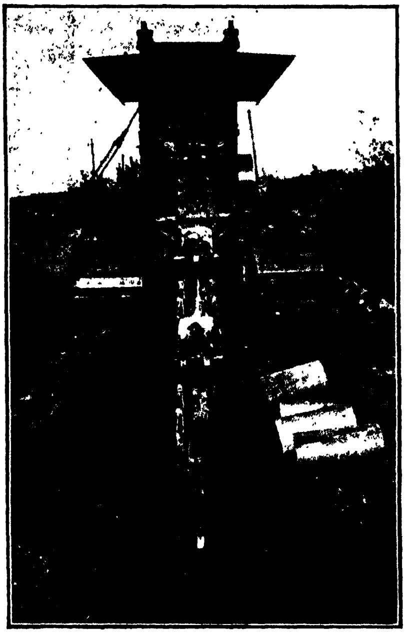


FIG. 316.—Endless chain-and-bucket machine digging a trench for highway drainage.

507. Draining Barnyards.—In providing drainage for barnyards, the first precaution to be taken is to see that all the roof water on the farm buildings is caught at the eaves by gutters which discharge directly into tile drains. Do not permit the water to fall from the eaves into the yard, as this makes draining the lots more difficult. Since stock tramp the soil while it is wet, puddling it and rendering it practically impervious, the same methods of drainage that are successful in cultivated fields will not produce results. The water must be allowed to enter the drains through surface inlets and silt basins, and where these are adequately placed and well guarded from the stock, good drainage will result. Shallow open ditches will also aid very materially.

If the barnyard and lots can be provided with a coating of gravel or sand, it will assist greatly. Where possible, the yards or parts of the yards should be paved with concrete.

508. Drainage as an Antimalarial Measure.—Drainage constitutes one of the most important and effective methods of combating mosquitoes because it eliminates the places where they breed. The U. S. Public Health Service maintains a staff of sanitary engineers, some of whom spend their entire time in this kind of work.

The requirements for success are, in some respects, different from those called for by ordinary agricultural drainage. (1) Surface water in ditches must be constantly kept in motion at a moderate speed; (2) water must not be allowed to stand in pools within pockets in ditch banks; (3) seepage lines on hillsides should be intercepted before the water has a chance to reach and saturate the ground surface; (4) all sloughs and shallow ponds must be drained whether it is agriculturally economical to do so or not; and (5) the water table must be lowered by underdrainage where necessary, in order to avoid stagnant water in shallow surface depressions.

These requirements give rise to the following principles that should be observed in practice:

1. The number of ditches used should be as few as possible.
2. They should have clean-cut, sloping sides, narrow bottoms, and straight courses wherever practicable.
3. Special attention should be given to maintenance, and, when this is unusually expensive, the ditch sides and bottom should be lined with concrete, stones, or wood planks. Lined ditches are especially effective in taking care of low water flow and are easily cleaned. They also require less inspection and, in most cases, are ultimately less costly.
4. Wet spots on the ground surface, which cannot be easily eradicated by drainage, should be entirely filled with earth.
5. The especial object of such drainage should be constantly kept in mind, and no opportunity should be overlooked to make it more effective.

In the nature of things, few projects will be completed, even under the most intelligent supervision, that function perfectly, and there will generally be need for auxiliary measures to supplement the work of the drainage ditches. Where the drains have been carefully designed and constructed, however, such supplementary work will be reduced to a minimum.

509. Drainage of Peat and Muck Marshes.—The drainage of peat and muck lands present special problems that require special treatment. Usually, no attempt to install tile is made until after several years of drainage by open ditches has removed most of the surplus water. When this occurs, these soils, being very loose and composed of fibrous vegetation, generally shrink from 30 to 40 per cent of their original depth above the plane of saturation as delineated by the drains.

If the subsoil is clay, tile drains are eventually placed at a depth of 3.5 feet and about 65 feet apart. There is danger of overdraining such soils on account of their loose structure, so that they dry out too much during drouths in the growing season. Valves are frequently installed in the laterals so that water may be held in them at such times. The top soil is benefited very much by mixing it with the clay subsoil. Such treatment improves the structure and also supplies potash, a fertilizing element which organic soils frequently lack.

If sand underlies the muck, about all the drainage that is necessary is to provide outlets. Deep open ditches, spaced at great intervals, are often satisfactory. If underdrains are used, they should be placed from 4 to 6 feet deep and at intervals of 150 to 200 feet. The danger of overdrainage is even greater than with clay subsoils, so much so that it may become necessary to irrigate after a few years. Nevertheless, it is generally recognized among authorities that drainage is the first requisite in subduing such lands and preparing them for agricultural production.

All peat and muck soils need to be first stirred and then compacted as much as possible as a preliminary step to cultivation.

510. Drainage of Irrigated Lands.—Paradoxical as it may seem, much land which is too dry to grow crops without irrigation also requires drainage. It is reliably estimated that 25 per cent (4,500,000 acres) of the area at present under irrigation in the United States is in need of such treatment.

Irrigation water is very commonly applied to the land in larger quantities than is absolutely necessary to saturate the root zone to its full capillary capacity. When this happens, the surplus sinks in the ground where it raises the water table and slowly travels underground to other land lying at a lower elevation.

In course of time, the water table is elevated to a point where it makes contact with the surface through capillary action, thus causing rapid evaporation to take place. Nearly all ground water in irrigated regions is heavily charged with soluble salts (mostly those of sodium), and, as the water evaporates, these salts are precipitated at or near the ground surface, frequently in quantities sufficient to prohibit the growth of crops. The only real remedy for land affected by alkali deposits is to provide deep drainage channels and redissolve the salts by copious applications of water which escapes through the drains. Once the soil is thoroughly flushed out, the drains prevent a recurrence of the trouble by not permitting the water table to rise within capillary reach of the surface. Of course, if the drains are installed in time, no damage will occur.

Tile lines placed 6 feet deep or more and from 200 to 300 feet apart have been found to give good satisfaction. Wherever necessary, open ditches or large tile are provided as outlets for the lateral drains.

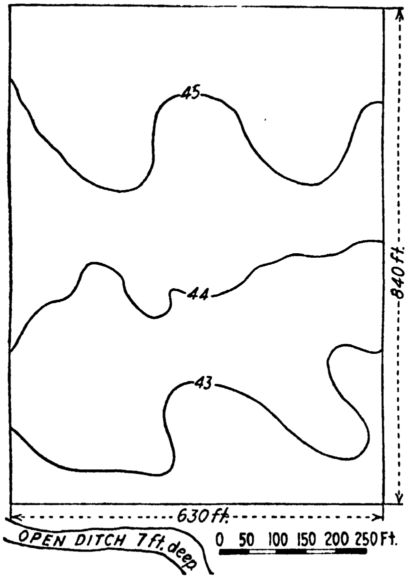
In the case of low-lying land which is damaged by water seeping from distant high land, the remedy consists in installing one or more lines of tile across the slope at the proper depth to intercept the seep water before it arrives at the land to be protected. Frequent borings and much careful study are necessary to determine the source of the harmful water so that the proper depth at which to place the intercepting drain or drains can be determined. As a rule, very little data can be obtained on the quantity of water to be removed. The proper size of tile to use for laterals and outlets must, consequently, be decided largely upon a basis of judgment and experience.

APPENDIX

Tile-drainage Problem 67

A plot of land 840 by 630 feet, topographical map of which is attached, is to be drained with tile in a systematic way. The following information relative to this piece of land is given:

Soil, heavy clay; annual rainfall, 30 inches; land 2 miles from nearest railroad station.



Design a system of tile on the accompanying map, putting lines of tile to scale and showing length and size of tile on each line. Prepare estimate of cost and other information called for by following the form given below.

Bill of Material

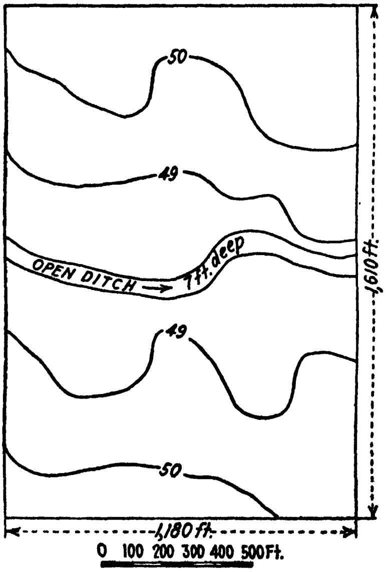
...... feet ...... inch tile @ $...... per thousand is $......
...... feet ...... inch tile @ $...... per thousand is $......
...... feet ...... inch tile @ $...... per thousand is $......
Total cost of tile.............................$......
...... feet ...... inch tile @ ...... pounds each is ...... tons
...... feet ...... inch tile @ ...... pounds each is ...... tons
...... feet ...... inch tile @ ...... pounds each is ...... tons
Total weight of tile..... .... tons

......tons hauled two miles @...... cents per ton mile is......$......
Laying ... feet ... inch tile ... inches deep @ ... per rod is.....$......
Laying ... feet ... inch tile ... inches deep @ ... per rod is.....$......
Laying ... feet ... inch tile ... inches deep @ ... per rod is.....$......
Total laying cost............................$......
Backfilling.... feet tile with team @.... cents per rod is $......
.... outlets @ $10 is...............................$......
.... catch drains @ $5............................$......
Total backfilling and accessories.............$......
Total cost of tile, hauling, laying, etc.........$......
Cost of engineering ... per cent of total cost $......
Acres in piece of land drained ...... *Total cost of project*......$......
Cost per acre to drain land ....

In this estimate, the following conditions were assumed from data given: drainage coefficient of ...... inch; tile placed ...... feet apart; tile placed ...... inches deep.

Tile-drainage Problem 68

A plot of land 1,610 by 1,180 feet, topographical map of which is attached, is to be drained in a systematic way. The following information relative to this piece of land is given.



Soil, alluvial gumbo; annual rainfall, 40 inches; land 4 miles from nearest railroad station.

Design a system of tile on the accompanying map, putting lines of tile to scale and showing length and size of tile on each line. Prepare estimate of cost and other information called for by following the form given below.

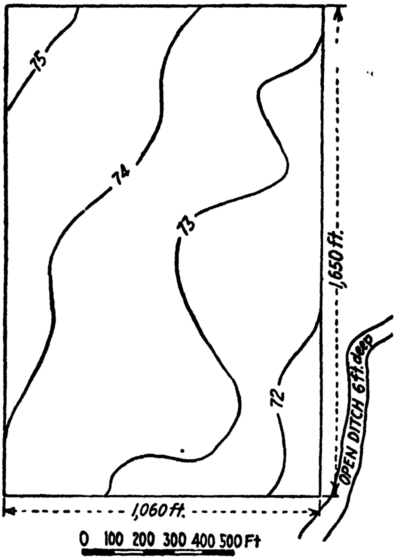
Bill of Material

...... feet ...... inch tile @ $...... per thousand is $......
...... feet ...... inch tile @ $...... per thousand is $......
...... feet ...... inch tile @ $...... per thousand is $......
Total cost of tile............................$......
...... feet ...... inch tile @ ...... pounds each is ...... tons
...... feet ...... inch tile @ ...... pounds each is ...... tons
...... feet ...... inch tile @ ...... pounds each is ...... tons
Total weight of tile.................. tons
.... tons hauled 4 miles @ ...... cents per ton mile is........$......
Laying ... feet ... inch tile ... inches deep @ ... per rod is $......
Laying ... feet ... inch tile ... inches deep @ ... per rod is $......
Laying ... feet ... inch tile ... inches deep @ ... per rod is $......
Total laying cost..........................$......
Backfilling ...... feet tile with team @ ...... cents per rod is ..$......
.... outlets @ $10 each is.................................$......
.... catch drains @ $5 each is...........................$......
Total backfilling and accessories..............$......
Total cost of tile, hauling, laying, etc..........$......
Cost of engineering .... per cent of total cost $......
Acres in piece of land drained ...... *Total cost of project*......$......
Cost per acre to drain land........

In this estimate, the following conditions were assumed from data given: drainage coefficient of ...... inch; tile placed ...... feet apart; tile placed ...... inches deep.

Tile-drainage Problem 69

A plot of land 1,060 by 1,650 feet, topographical map of which is attached, is to be drained with tile in a systematic way. The following information relative to this piece of land is given:



Soil, sandy loam with clay subsoil; annual rainfall—50 inches; land 10 miles from nearest railroad station. Design a system of tile on the accompanying map—putting lines of tile to scale, showing length and size of tile on each line. Prepare estimate of cost and other information called for by following form given below:

BILL OF MATERIAL

...... feet ...... inch tile @ $...... per thousand is $......

...... feet ...... inch tile @ $...... per thousand is $......

...... feet ...... inch tile @ $...... per thousand is $......

Total cost of tile.......................... $......

...... feet ...... inch tile @ ...... pounds each is ...... tons

...... feet ...... inch tile @ ...... pounds each is ...... tons

...... feet ...... inch tile @ ...... pounds each is ...... tons

Total weight of tile.................... tons

...... tons tile hauled 10 miles @ ...... cents per ton is........ $......

Laying ... feet ... inch tile ... inches deep @ ... per rod is $......

Laying ... feet ... inch tile ... inches deep @ ... per rod is $......

Laying ... feet ... inch tile ... inches deep @ ... per rod is $......

Total laying cost.......................... $......

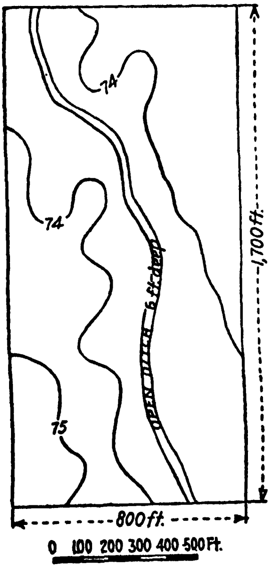
Backfilling ... feet tile with team @ ... cents per rod is $......
.... outlets @ $10 is..............................$......
.... catch drains @ $5 is.........................$......
Total backfilling and accessories.............$......
Total cost of tile, hauling, laying, etc.........$......
Cost of engineering ... per cent of total cost..$......
Acres in piece of land drained...... *Total cost of project*.......$......
Cost per acre to drain land ....

In this estimate the following conditions were assumed from data given: drainage coefficient of ...... inch; tile placed ...... feet apart; tile placed ...... inches deep.

Tile-drainage Problem 70

A plot of land 800 by 1,700 feet, topographical map of which is attached, is to be drained with tile in a systematic way. The following information relative to this piece of land is given:

Soil, sandy loam, with subsoil of similar nature; annual rainfall, 60 inches; land 8 miles from nearest railroad station.



Design a system of tile drainage on the accompanying map, putting lines of tile to scale and showing length and size of tile on each line. Prepare estimate of cost and other information called for by following the form given on the following page.

Bill of Material

...... feet ...... inch tile @ $...... per thousand is $......
...... feet ...... inch tile @ $...... per thousand is $......
...... feet ...... inch tile @ $...... per thousand is $......
Total cost of tile.............................$......
...... feet ...... inch tile @ ...... pounds each is ..... tons
...... feet ...... inch tile @ ...... pounds each is ..... tons
...... feet ...... inch tile @ ...... pounds each is ..... tons
Total weight of tile, ...tons.......$......
...... tons tile hauled 8 miles @ ... cents per ton mile is........$......
Laying ... feet ... inch tile ... inches deep @ ... per rod is $......
Laying ... feet ... inch tile ... inches deep @ ... per rod is $......
Laying ... feet ... inch tile ... inches deep @ ... per rod is $......
Total laying cost........................$......
Backfilling ... feet tile with team @ ... cents per rod is $......
.... outlets @ $10 each is........................$......
.... catch drain @ $5 each is.....................$......
Total backfilling and accessories.............$......
Total cost of tile, hauling, laying, etc.........$......
Cost of engineering ... per cent of total cost.$......
Acres in piece of land drained ...... *Total cost of project*......$......
Cost per acre to drain land ....

In this estimate the following conditions were assumed from data given: drainage coefficient of ... inch; tile placed ... feet apart; tile placed ... inches deep.

TABLE 46.—NATURAL TRIGONOMETRIC FUNCTIONS

Angle, degrees	Sin.	Cosec.	Tan.	Cotan.	Sec.	Cos.	Angle, degrees
0	0.000	....	0.000	....	1.000	1.000	90
1	0.017	57.30	0.017	57.29	1.000	1.000	89
2	0.035	28.65	0.035	28.64	1.001	0.999	88
3	0.052	19.11	0.052	19.08	1.001	0.999	87
4	0.070	14.34	0.070	14.30	1.002	0.998	86
5	0.087	11.47	0.087	11.43	1.004	0.996	85
6	0.105	9.567	0.105	9.514	1.006	0.995	84
7	0.122	8.206	0.123	8.144	1.008	0.993	83
8	0.139	7.185	0.141	7.115	1.010	0.990	82
9	0.156	6.392	0.158	6.314	1.012	0.988	81
10	0.174	5.759	0.176	5.671	1.015	0.985	80
11	0.191	5.241	0.194	5.145	1.019	0.982	79
12	0.208	4.810	0.213	4.705	1.022	0.978	78
13	0.225	4.445	0.231	4.331	1.026	0.974	77
14	0.242	4.134	0.249	4.011	1.031	0.970	76
15	0.259	3.864	0.268	3.732	1.035	0.966	75
16	0.276	3.628	0.287	3.487	1.040	0.961	74
17	0.292	3.420	0.306	3.271	1.046	0.956	73
18	0.309	3.236	0.325	3.078	1.051	0.951	72
19	0.326	3.072	0.344	2.904	10.58	0.946	71
20	0.342	2.924	0.364	2.747	1.064	0.940	70
21	0.358	2.790	0.384	2.605	1.071	0.934	69
22	0.375	2.669	0.404	2.475	1.079	0.927	68
23	0.391	2.559	0.424	2.356	1.086	0.921	67
24	0.407	2.459	0.445	2.246	1.095	0.914	66
25	0.423	2.366	0.466	2.145	1.103	0.906	65
26	0.438	2.281	0.488	2.050	1.113	0.899	64
27	0.454	2.203	0.510	1.963	1.122	0.891	63
28	0.469	2.130	0.532	1.881	1.133	0.883	62
29	0.485	2.063	0.554	1.804	1.143	0.875	61
30	0.500	2.000	0.577	1.732	1.155	0.866	60
31	0.515	1.942	0.601	1.664	1.167	0.857	59
32	0.530	1.887	0.625	1.600	1.179	0.848	58
33	0.545	1.836	0.649	1.540	1.192	0.839	57
34	0.559	1.788	0.675	1.483	1.206	0.829	56
35	0.574	1.743	0.700	1.428	1.221	0.819	55
36	0.588	1.701	0.727	1.376	1.236	0.809	54
37	0.602	1.662	0.754	1.327	1.252	0.799	53
38	0.616	1.624	0.781	1.280	1.269	0.788	52
39	0.629	1.589	0.810	1.235	1.287	0.777	51
40	0.643	1.556	0.839	1.192	1.305	0.766	50
41	0.656	1.524	0.869	1.150	1.325	0.755	49
42	0.669	1.494	0.900	1.111	1.346	0.743	48
43	0.682	1.466	0.933	1.072	1.367	0.731	47
44	0.695	1.440	0.966	1.036	1.390	0.719	46
45	0.707	1.414	1.000	1.000	1.414	0.707	45
	Cos.	Sec.	Cotan.	Tan.	Cosec.	Sin.	Angle

TABLE 47.—TWO-THIRDS POWERS OF NUMBERS
(For use in Manning's Formula)

Number	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.046	.074	.097	.117	.136	.153	.170	.186	.201
.1	.215	.229	.243	.256	.269	.282	.295	.307	.319	.331
.2	.342	.353	.364	.375	.386	.397	.407	.418	.428	.438
.3	.448	.458	.468	.477	.487	.497	.506	.515	.525	.534
.4	.543	.552	.561	.570	.578	.587	.596	.604	.613	.622
.5	.630	.638	.647	.655	.663	.671	.679	.687	.695	.703
.6	.711	.719	.727	.735	.743	.750	.758	.765	.773	.781
.7	.788	.796	.803	.811	.818	.825	.832	.840	.847	.855
.8	.862	.869	.876	.883	.890	.897	.904	.911	.918	.925
.9	.932	.939	.946	.953	.960	.966	.973	.980	.987	.993
1.0	1.000	1.007	1.013	1.020	1.027	1.033	1.040	1.046	1.053	1.059
1.1	1.065	1.072	1.078	1.085	1.091	1.097	1.104	1.110	1.117	1.123
1.2	1.129	1.136	1.142	1.148	1.154	1.160	1.167	1.173	1.179	1.185
1.3	1.191	1.197	1.203	1.209	1.215	1.221	1.227	1.233	1.239	1.245
1.4	1.251	1.257	1.263	1.269	1.275	1.281	1.287	1.293	1.299	1.305
1.5	1.310	1.316	1.322	1.328	1.334	1.339	1.345	1.351	1.357	1.362
1.6	1.368	1.374	1.379	1.385	1.391	1.396	1.402	1.408	1.413	1.419
1.7	1.424	1.430	1.436	1.441	1.447	1.452	1.458	1.463	1.469	1.474
1.8	1.480	1.485	1.491	1.496	1.502	1.507	1.513	1.518	1.523	1.529
1.9	1.534	1.539	1.545	1.550	1.556	1.561	1.566	1.571	1.577	1.582
2.0	1.587	1.593	1.598	1.603	1.608	1.613	1.619	1.624	1.629	1.634
2.1	1.639	1.645	1.650	1.655	1.660	1.665	1.671	1.676	1.681	1.686
2.2	1.691	1.697	1.702	1.707	1.712	1.717	1.722	1.727	1.732	1.737
2.3	1.742	1.747	1.752	1.757	1.762	1.767	1.772	1.777	1.782	1.787
2.4	1.792	1.797	1.802	1.807	1.812	1.817	1.822	1.827	1.832	1.837
2.5	1.842	1.847	1.852	1.857	1.862	1.867	1.871	1.876	1.881	1.886
2.6	1.891	1.896	1.900	1.905	1.910	1.915	1.920	1.925	1.929	1.934
2.7	1.939	1.944	1.949	1.953	1.958	1.963	1.968	1.972	1.977	1.982
2.8	1.987	1.992	1.996	2.001	2.006	2.010	2.015	2.020	2.024	2.029
2.9	2.034	2.038	2.043	2.048	2.052	2.057	2.062	2.066	2.071	2.075
3.0	2.080	2.085	2.089	2.094	2.099	2.103	2.108	2.112	2.117	2.122
3.1	2.126	2.131	2.135	2.140	2.144	2.149	2.153	2.158	2.163	2.167
3.2	2.172	2.176	2.180	2.185	2.190	2.194	2.199	2.203	2.208	2.212
3.3	2.217	2.221	2.226	2.230	2.234	2.239	2.243	2.248	2.252	2.257
3.4	2.261	2.265	2.270	2.274	2.279	2.283	2.288	2.292	2.296	2.301
3.5	2.305	2.310	2.314	2.318	2.323	2.327	2.331	2.336	2.340	2.345
3.6	2.349	2.353	2.358	2.362	2.366	2.371	2.375	2.379	2.384	2.388
3.7	2.392	2.397	2.401	2.405	2.409	2.414	2.418	2.422	2.427	2.431
3.8	2.435	2.439	2.444	2.448	2.452	2.457	2.461	2.465	2.469	2.474
3.9	2.478	2.482	2.486	2.490	2.495	2.499	2.503	2.507	2.511	2.516
4.0	2.520	2.524	2.528	2.532	2.537	2.541	2.545	2.549	2.553	2.558
4.1	2.562	2.566	2.570	2.574	2.579	2.583	2.587	2.591	2.595	2.599
4.2	2.603	2.607	2.611	2.616	2.620	2.624	2.628	2.632	2.636	2.640
4.3	2.644	2.648	2.653	2.757	2.661	2.665	2.669	2.673	2.677	2.681
4.4	2.685	2.689	2.693	2.698	2.702	2.706	2.710	2.714	2.718	2.722
4.5	2.726	2.730	2.734	2.738	2.742	2.746	2.750	2.754	2.758	2.762
4.6	2.766	2.770	2.774	2.778	2.782	2.786	2.790	2.794	2.798	2.802
4.7	2.806	2.810	2.814	2.818	2.822	2.826	2.830	2.834	2.838	2.842
4.8	2.846	2.850	2.854	2.858	2.862	2.865	2.869	2.873	2.877	2.881
4.9	2.885	2.889	2.893	2.897	2.901	2.904	2.908	2.912	2.916	2.920

TABLE 48.—SQUARE ROOTS OF DECIMAL NUMBERS
(For use in Manning's Formula)

Number	.−0	.−1	.−2	.−3	.−4	.−5	.−6	.−7	.−8	.−9
.00001	.003162	.003317	.003464	.003606	.003742	.003873	.004000	.004123	.004243	.004359
.00002	.004472	.004583	.004690	.004796	.004899	.005000	.005099	.005196	.005292	.005385
.00003	.005477	.005568	.005657	.005745	.005831	.005916	.006000	.006083	.006164	.006245
.00004	.006325	.006403	.006481	.006557	.006633	.006708	.006782	.006856	.006928	.007000
.00005	.007071	.007141	.007211	.007280	.007348	.007416	.007483	.007550	.007616	.007681
.00006	.007746	.007810	.007874	.007937	.008000	.008062	.008124	.008185	.008246	.008307
.00007	.008367	.008426	.008485	.008544	.008602	.008660	.008718	.008775	.008832	.008888
.00008	.008944	.009000	.009055	.009110	.009165	.009220	.009274	.009327	.009381	.009434
.00009	.009487	.009539	.009592	.009644	.009695	.009747	.009798	.009849	.009899	.009950
.00010	.010000	.010050	.010100	.010149	.010198	.010247	.010296	.010344	.010392	.010440
.0001	.01000	.01049	.01095	.01140	.01183	.01225	.01265	.01304	.01342	.01378
.0002	.01414	.01449	.01483	.01517	.01549	.01581	.01612	.01643	.01673	.01703
.0003	.01732	.01761	.01789	.01827	.01844	.01871	.01897	.01924	.01949	.01975
.0004	.02000	.02025	.02049	.02074	.02098	.02121	.02145	.02168	.02191	.02214
.0005	.02236	.02258	.02280	.02302	.02324	.02345	.02366	.02387	.02408	.02429
.0006	.02449	.02470	.02490	.02510	.02530	.02550	.02569	.02588	.02608	.02627
.0007	.02646	.02665	.02683	.02702	.02720	.02739	.02757	.02775	.02793	.02811
.0008	.02828	.02846	.02864	.02881	.02898	.02915	.02933	.02950	.02966	.02983
.0009	.03000	.03017	.03033	.03050	.03066	.03082	.03098	.03114	.03130	.03146
.0010	.03162	.03178	.03194	.03209	.03225	.03240	.03256	.03271	.03286	.03302
.001	.03162	.03317	.03464	.03606	.03742	.03873	.04000	.04123	.04243	.04359
.002	.04472	.04583	.04690	.04796	.04899	.05000	.05009	.05196	.05292	.05385
.003	.05477	.05568	.05657	.05745	.05831	.05916	.06000	.06083	.06164	.06245
.004	.06325	.06403	.06481	.06557	.06633	.06708	.06782	.06856	.06928	.07000
.005	.07071	.07141	.07211	.07280	.07348	.07416	.07483	.07550	.07616	.07681
.006	.07756	.07810	.07874	.07937	.08000	.08062	.08124	.08185	.08246	.08307
.007	.08367	.08426	.08485	.08544	.08602	.08660	.08718	.08775	.08832	.08888
.008	.08944	.09000	.09055	.09110	.09165	.09220	.09274	.09327	.09381	.09434
.009	.09487	.09539	.09592	.09644	.09695	.09747	.09798	.09849	.09899	.09950
.010	.10000	.10050	.10100	.10149	.10198	.10247	.10296	.10344	.10392	.10440
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1304	.1342	.1378
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.2811
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146
.10	.3162	.3178	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302

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